

*Tech Library*

HDL

RIA-77-U1213

# TECHNICAL LIBRARY

## Status of the Tactical Environment Multiple Systems Evaluation Program (TEMSEP)

October 1977

DTIC QUALITY INSPECTED

This work was sponsored in part by the Defense Nuclear Agency  
under subtask R99QAXEB088, EMP Interaction and Coupling Phenomenology.

### DISTRIBUTION STATEMENT A

Approved for public release  
Distribution Unlimited



U.S. Army Materiel Development  
and Readiness Command

HARRY DIAMOND LABORATORIES

Adelphi, Maryland 20783

19970723 195

VED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

HDL-PR-77-2—Status of the Tactical Environment Multiple Systems Evaluation  
Program (TEMSEP), by John N. Bombardt, Jr., John F. W. Dietz, George Merkel, and Daniel J. Spohn

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturers' or trade names does not constitute an official indorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE   |                       | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM   |
|---|-----------------------|---|
| 1. REPORT NUMBER<br>HDL-PR-77-2   | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER   |
| 4. TITLE (and Subtitle)<br><br>Status of the Tactical Environment Multiple Systems Evaluation Program (TEMSEP)  |                       | 5. TYPE OF REPORT & PERIOD COVERED<br>Progress Report   |
| 7. AUTHOR(s)<br>John N. Bombardt, Jr.      George Merkel<br>John F. W. Dietz          Daniel J. Spohn   |                       | 6. PERFORMING ORG. REPORT NUMBER  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Harry Diamond Laboratories<br>2800 Powder Mill Road<br>Adelphi, MD 20783   |                       | 8. CONTRACT OR GRANT NUMBER(s)<br>DA: 1L1621188AH75   |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Defense Nuclear Agency<br>Washington, DC 20305   |                       | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>Program Ele. 6.27.04.H<br>Program Ele. 6.21.18.A |
| 14. CONTROLLING OFFICE NAME AND ADDRESS<br>US Army Materiel Development & Readiness Command<br>5001 Eisenhower Avenue<br>Alexandria, VA 22333   |                       | 12. REPORT DATE<br>October 1977   |
|   |                       | 13. NUMBER OF PAGES<br>55   |
|   |                       | 15. SECURITY CLASS. (of this report)<br>Unclassified  |
|   |                       | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE  |
| 16. DISTRIBUTION STATEMENT (of this Report)<br><br>Approved for public release; distribution unlimited.   |                       |   |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)  |                       |   |
| 18. SUPPLEMENTARY NOTES<br>DRCMS Code: 36AA.7210062704      This work was sponsored in part by<br>DRCMS Code: 612118.H750011      the Defense Nuclear Agency under<br>HDL Project: E057E3                  subtask R99QAXEB088, EMP Interaction<br>HDL Project: X757E7                  and Coupling Phenomenology.   |                       |   |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>EMP<br>Tactical nuclear threats<br>Simulation<br>Flash x ray  |                       |   |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>This report discusses technical progress made during FY76 under the Defense Nuclear Agency (DNA) sponsored Tactical Environment Multiple Systems Evaluation Program (TEMSEP). The long and short range goals of the program are presented with particular emphasis on the topics of instrumentation in an ionizing radiation environment, basic phenomena associated with the electromagnetic pulse (EMP) generation within the nuclear source region, and |                       |   |

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

laboratory simulation of the electromagnetic environment associated with the nearby (endoatmospheric) detonation of a nuclear weapon. Experiments used the AURORA Flash X-Ray Facility as a radiation source. Notable milestones accomplished during FY76 were the experimental verification of the existence of the "boundary layer" phenomenon and verification of electromagnetic coupling models for simple structures.

UNCLASSIFIED

2 SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## FOREWORD

The work reported here was sponsored primarily by the Defense Nuclear Agency (DNA) under subtask R99QAXEB088. The authors acknowledge the guidance and contributions of two DNA Project Officers: William Adams in the early stages of program formulation and W. D. Wilson in insuring program continuity during 1976. Also, we are appreciative of help received from Paul Caldwell and his staff at the Harry Diamond Laboratories AURORA Flash X-Ray Facility; in particular, we thank Stewart Graybill, Klaus Kerris, and Denis Whittaker for their contributions during our AURORA experiments. Within our own organization, Laboratory 1000, Robert Pfeffer managed the work during much of FY76 and Leedy Ambrose and Joseph Capobianco provided us with valuable experimental assistance. Finally, we take this opportunity to express our thanks to Jean Ciccarelli for preparation of the original manuscript.

## CONTENTS

|  | <u>Page</u> |
|--|-------------|
| FOREWORD . . . . .   | 3           |
| 1. PROGRAMMATIC OVERVIEW . . . . .   | 7           |
| 1.1 Objectives and Scope . . . . .   | 7           |
| 1.2 Approach . . . . .   | 8           |
| 2. PROGRAMMATIC MILESTONES . . . . .   | 11          |
| 2.1 December Test . . . . .  | 11          |
| 2.2 March Test . . . . .   | 14          |
| 2.3 Mission Research Corp/AURORA Memorandums . . . . .   | 19          |
| 2.4 Code Development Contracts . . . . .   | 19          |
| 2.5 Environment Code NEMP . . . . .  | 21          |
| 2.6 Interaction and Coupling Analyses of Lance Missile System<br>and AN/GRC-106 Radio System . . . . . | 21          |
| 3. TECHNICAL MILESTONES . . . . .  | 23          |
| 3.1 Boundary-Layer Conclusions and Results . . . . .   | 23          |
| 3.2 Compton Current Measurement . . . . .  | 30          |
| 3.3 Electric-Field Sensor . . . . .  | 33          |
| 3.4 High-Impedence Voltage Measurements . . . . .  | 35          |
| 3.4.1 Method 1 . . . . .   | 36          |
| 3.4.2 Method 2 . . . . .   | 36          |
| 3.5 Interaction and Coupling Theory . . . . .  | 37          |
| 3.5.1 Rectangular Configuration . . . . .  | 37          |
| 3.5.2 Concentric Cylinders . . . . .   | 37          |
| 3.6 Direct versus Electromagnetic Coupling Mode Dominance . . . .                                      | 38          |
| 3.7 Data Reduction . . . . .   | 41          |
| 3.8 Measurement of Electric Field Produced by Electrically Free<br>Floating Pig . . . . .              | 41          |
| 4. PLANS . . . . .   | 47          |
| LITERATURE CITED . . . . .   | 48          |
| DISTRIBUTION . . . . .   | 49          |

## FIGURES

|  |    |
|--|----|
| 1 Regions of valid atmospheric test data and recent<br>underground test data . . . . . | 9  |
| 2 Compton diode . . . . .  | 11 |

# FIGURES (Cont'd)

|  | <u>Page</u> |
|--|-------------|
| 3 Cathode follower . . . . .                                     | 13          |
| 4 Concentric box test geometry . . . . .                         | 14          |
| 5 Concentric cylinder test geometry . . . . .                    | 15          |
| 6 Bench test . . . . .   | 15          |
| 7 One-turn Rogowski coil . . . . .                               | 16          |
| 8 Pie-pan sensor . . . . .                                       | 18          |
| 9 Possible simulation scheme . . . . .                           | 19          |
| 10 Model of boundary layer . . . . .                             | 24          |
| 11 Pie-pan sensor . . . . .                                      | 25          |
| 12 Pie-pan model . . . . .                                       | 28          |
| 13 Method of filling pie-pan sensor with humid air . . . . .     | 29          |
| 14 Method of preventing H <sub>2</sub> O precipitation . . . . . | 29          |
| 15 Pie-pan response . . . . .                                    | 30          |
| 16 $\dot{J}$ sensor . . . . .                                    | 32          |
| 17 Compton-current time history . . . . .                        | 33          |
| 18 Electric-field sensor . . . . .                               | 34          |
| 19 Total axial current on inner cylinder . . . . .               | 38          |
| 20 Inductive coupling . . . . .                                  | 40          |
| 21 Whittaker $\dot{E}$ sensor . . . . .                          | 43          |
| 22 Floating pig . . . . .  | 44          |
| 23 Output of $\dot{E}$ sensor . . . . .                          | 44          |
| 24 Integration of $\dot{E}$ sensor . . . . .                     | 45          |
| 25 Charged pig . . . . .   | 46          |

## TABLE

|                                  |    |
|----------------------------------|----|
| I Peak Coupled Current . . . . . | 37 |
|----------------------------------|----|

## 1. PROGRAMMATIC OVERVIEW

### 1.1 Objectives and Scope

The Tactical Environment Multiple Systems Evaluation Program (TEMSEP) is jointly funded at the Harry Diamond Laboratories (HDL) by the Army and the Defense Nuclear Agency (DNA) and is directed toward vulnerability assessments and hardening of tactical military equipment for tactical nuclear threats. Specifically, the ultimate goals of TEMSEP are these:

a. Develop methods to assess by analysis and experimentation the electromagnetic pulse (EMP) vulnerabilities of military equipment for endoatmospheric nuclear threats

b. Predict EMP vulnerabilities of critical military equipment to endoatmospheric nuclear threats

c. Determine the relative effects on critical military equipment of endoatmospheric and exoatmospheric nuclear threats

d. Evaluate the effectiveness of EMP hardening measures associated with exoatmospheric nuclear threats for protection against endoatmospheric nuclear threats

e. Recommend appropriate EMP hardening measures to insure system survivability in a tactical nuclear environment.

In general, the DNA-sponsored portion of TEMSEP addresses the following matters: (1) the definition of EMP environmental criteria for tactical scenarios, (2) the development of interaction and coupling technology for critical tactical systems in the intermediate region of "weak" Compton currents, and (3) the evaluation of the feasibility of simulating tactical source-region EMP environments by using the HDL AURORA Flash X-Ray Facility. The Army-sponsored portion of TEMSEP, on the other hand, is concerned with vulnerability assessments and hardening recommendations for actual Army equipment.

The purpose of this report is to review TEMSEP and the progress made in this program during FY76, with the primary emphasis on the applied research which was sponsored by DNA. Interaction and coupling studies, damage analyses, and vulnerability assessments of the Lance Missile System and the AN/GRC-106 Radio System were performed in TEMSEP during FY76 under sponsorship of the Army; this Army-sponsored work is not discussed at length in this report. Some of the DNA-sponsored work done in TEMSEP during FY76 has been reported in the open literature.<sup>1</sup>

---

<sup>1</sup>J. F. W. Dietz, G. Merkel, and D. Spohn, *Radiation Induced Coupling to a Truncated Cylinder within a Cylinder*, IEEE Trans. Nucl. Sci., NS-23 (December 1976).



## 1.2 Approach

The total programmatic approach of TEMSEP, is as follows:

a. From the defense intelligence community and related EMP vulnerability assessment and hardening programs (such as the Multiple Systems Evaluation Program<sup>1</sup>), identify critical foreign and domestic tactical systems.

b. Define the characteristics of these equipments which contribute to their susceptibility to tactical nuclear threats.

c. Develop the interaction and coupling technology necessary to analyze such characteristics and to determine system vulnerability.

d. Develop the experimental and theoretical techniques necessary to evaluate system susceptibility on the terminal and circuit level.

e. Establish susceptibilities and assess vulnerabilities of a tractable set of critical foreign and domestic systems involved in tactical scenarios.

f. Evaluate the effectiveness of conventional hardening measures (such as filtering, terminal protection, and isolation) for tactical EMP threats, and develop generic hardening measures applicable to many subsystems of the same general type.

g. Identify research requirements (such as interaction and coupling phenomena, circuit and damage models, and device development for terminal and circuit protection) resulting from the technology voids which impede meaningful vulnerability assessment and hardening of critical domestic systems.

A key step in the above programmatic approach is the development of the interaction and coupling technology necessary to assess system vulnerability. This step involves not only the development of experimental and theoretical techniques for predicting and evaluating responses of dominant interaction and coupling mechanisms (as these appear in actual systems), but also the conception and experimental verification of technically feasible schemes for simulating tactical source-region EMP environments. With regard to the latter, no existing threat-relatable EMP simulator can produce all of the electromagnetic characteristics of a tactical near-surface nuclear detonation, including the proper electromagnetic field components, time-varying air conductivity, and Compton current. In addition, no data gathered during atmospheric tests or during recent underground tests are pertinent (with respect to both the time and the dose) to the

<sup>1</sup>J. F. W. Dietz, G. Merkel, and D. Spohn, *Radiation Induced Coupling to a Truncated Cylinder within a Cylinder*, IEEE Trans. Nucl. Sci., NS-23 (December 1976).

tactical source region, as shown in figure 1. Nevertheless, intelligent use of flash x-ray machines (in particular, the AURORA Facility) can yield meaningful information that can be used to validate theory or guide the development of theoretical source-region coupling models. In addition, augmentation of the AURORA environment may be possible to simulate a tactical source-region EMP environment which is appropriate for certain types of critical systems.

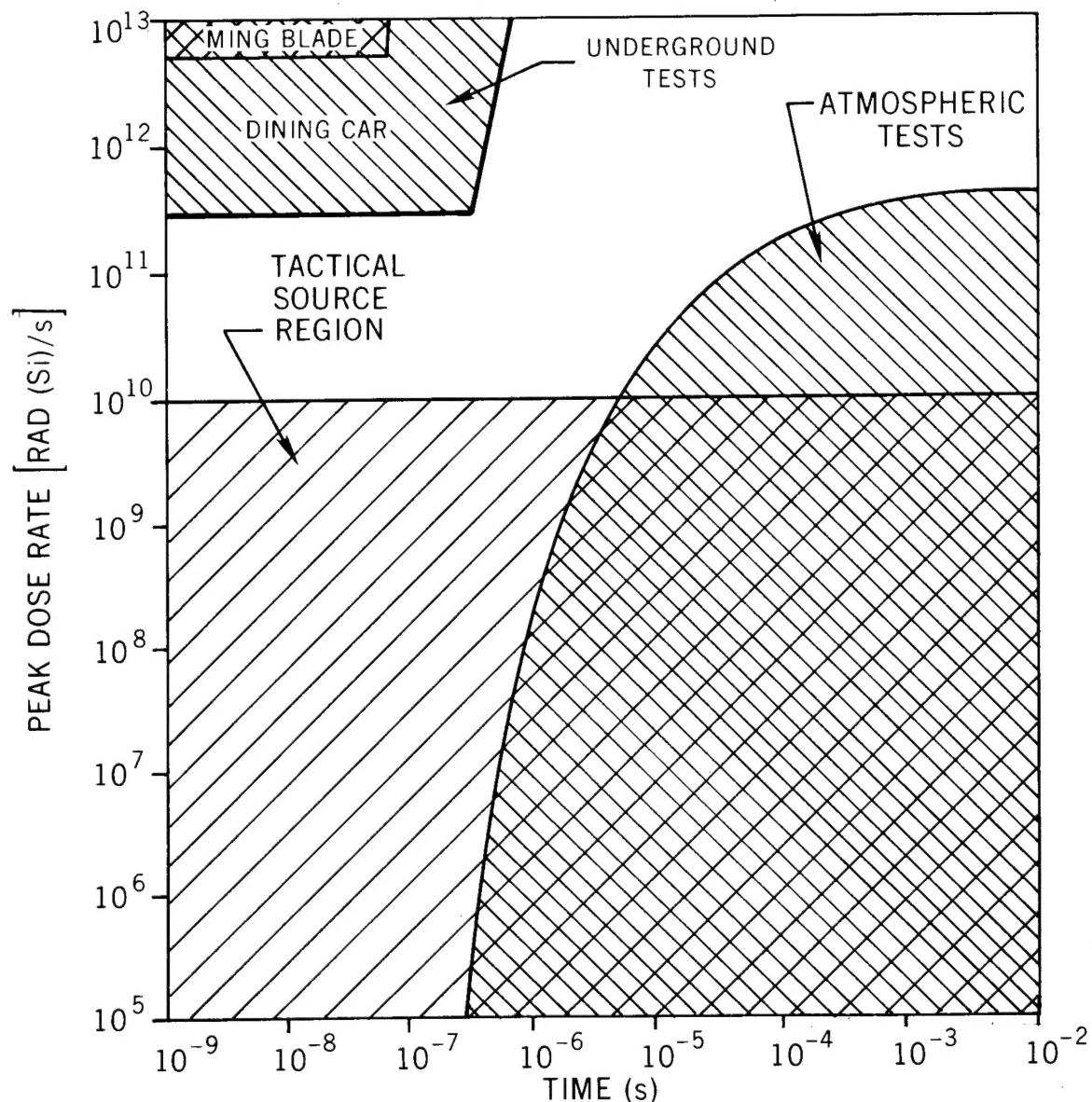


Figure 1. Regions of valid atmospheric test data and recent underground test data (according to R. Shaffer of R and D Associates) and region of interest for tactical source region related research.

Thus, several areas of experimental investigation are important to programmatic success, each of which is designed to contribute to the eventual ability to adequately assess the vulnerability of military equipment to the tactical nuclear threat. These areas are the following:

a. the development of instrumentation for making electromagnetic measurements in the presence of ionizing radiation

b. controlled diagnostic experiments designed to validate or guide theoretical developments (by using the AURORA Facility, the High Intensity Flash X-Ray Facility (HIFX), or both)

c. Comprehensive experimental characterization of the AURORA environment with respect to the gamma source, the electromagnetic field, air conductivity, and Compton current

d. Proof-of-principle experiments designed to evaluate the technical feasibility of simulation concepts involving the AURORA Facility

Although most of HDL's technical effort expended for DNA in FY76 was connected with the areas of experimental investigation listed above, the development of theoretical techniques for predicting and evaluating responses of dominant interaction and coupling mechanisms also received a good deal of attention in FY76 and figures prominently in TEMSEP. The areas of theoretical investigation that presently appear to be of particular programmatic significance are these:

a. The relative importance of electromagnetic excitation (the electromagnetic field and transient air conductivity in the absence of the system) and direct excitation (gamma and Compton-electron) of systems subjected to tactical nuclear threats

b. Evaluation and improvement of state-of-the-art numerical tools for tactical applications

c. Evaluation and improvement of time-phase (particularly, quasi-static) analytical and numerical tools for tactical applications.

The first area of theoretical investigation is concerned with the significance of detailed Monte Carlo sources, self-consistency, and charge-depletion (boundary) layers in a tactical context. The last two areas of theoretical investigation are concerned with establishing the adequacy of existing theoretical techniques and improving them for tactical applications.

## 2. PROGRAMMATIC MILESTONES

During FY76, several programmatic milestones were identified. These included the successful completion of two AURORA runs (December and March), the awarding of several supporting contracts, the completion of system coupling analyses (Lance and the AN/GRC-106), the running of a new environment code (NEMP), and the identification of potential problem areas (Mission Research Corp. (MRC)/AURORA memorandums and boundary layer reports). Each milestone by itself does not represent a technical accomplishment, but rather is an identifiable effort which is important only in an overall programmatic context. The technical milestones represent the true technical progress made in this program.

### 2.1 December Test

During early December 1975, a series of experiments was conducted at the AURORA Facility with the primary purpose of determining the adequacy of new instruments which had been designed to function in the radiation environment. In addition, coupling experiments and AURORA gamma-source measurements were carried out. With respect to the four general areas of research addressed in FY76 (coupling, instrumentation, basic phenomena, and simulation), the experiments addressed three of them (coupling, instrumentation, and simulation).

New instrumentation, constructed for use in the March 1976 test, was checked out in the radiation environment. This included a cathode follower, to be used in connection with a Tektronix voltage probe to make high-impedance voltage measurements, and a Compton diode and a collimated Rogowski coil, to be used to measure the Compton current in the air. Response measurements of a concentric box geometry also were made with the intention of being used for comparisons with theory. In simulation, a series of collimated dosimeter measurements was performed to provide information useful for characterizing the AURORA source.

The Compton diode constructed for this test (fig. 2) consisted of an aluminum cylinder 15 cm in diameter with a tungsten collector 6.3 cm in diameter. To collimate the current driving the sensor, Pb (10 cm thick) was used.

The collimated Rogowski coil comprised an Adams Electronic Corp. (ADELCO) current probe (of radius 1.27 cm) collimated with 10 cm of Pb. The probe and Pb were placed in an aluminum cylinder for convenience.

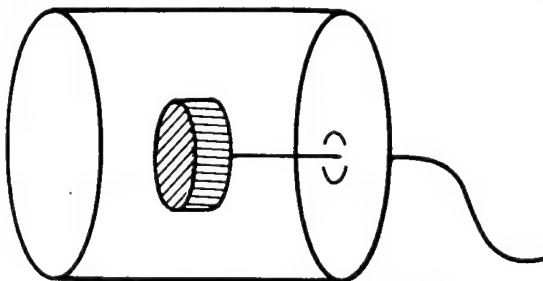


Figure 2. Compton diode.

A cathode follower circuit was constructed to be used as an impedance matching network to drive the low-impedance cable from a high-impedance source while maintaining minimal signal loss (fig. 3). The device was used with a Tektronix P6003 probe to measure the voltage buildup on the center box of the concentric box test geometry used in coupling experiments. The voltage probe was exposed to the unattenuated AURORA radiation within the test geometry, but the cathode follower was provided shielding by being placed inside the center of a stack of Pb bricks. In this configuration, the cathode follower was exposed to a total dose of approximately 5 rads (Si) ( $3 \times 10^7$  rads (Si)/s peak).

Coupling experiments used the basic concentric box geometry shown in figure 4. It consisted of a box 15.24 cm to a side constructed of 0.63-cm aluminum, suspended on nylon rope in a 66-cm square conducting upper chamber of a two-chamber radio frequency interference (RFI) shielded box. The inner aluminum box, located in the center of the upper chamber, was connected with a thin wire to a BNC feed-through cable to the lower chamber where the cathode followers were located. The two chambers were separated by a 2.54-cm-thick aluminum partition. The suspended aluminum box was used in two modes: one with the box empty so that it was thin with respect to the absorption of gamma radiation and another with the box filled with Pb so that it was thick with respect to gamma radiation. The shielded box was symmetrically placed in the AURORA test cell, elevated so that the center of the upper chamber (and the suspended inner aluminum box) was on the axis of the AURORA radiation. In this configuration, the front was exposed to a total dose of approximately 700 rads (Si). The "open-circuit" voltage and short-circuit current were measured on the inner box. In addition, Rogowski coils (to measure the Compton current) and Moebius loops (to measure the magnetic field) were placed at various locations within the upper chamber.

Although it may sometimes be assumed so, the AURORA Facility's "hot spot" is not a point source of radiation. A more reasonable assumption is that it is a disk source of some effective area. To determine this area, an experiment was designed by using thermoluminescent dosimeters (TLD's) placed in holes drilled through various thicknesses of Pb bricks. By measuring the dose and dose rates at the same distance from the source with 0, 5.08, and 10.16 cm of collimation, the effective area of the source can be calculated directly by geometrical considerations.

Data obtained during the December test contributed to some of the significant conclusions that were drawn based on the consideration of the total FY76 effort. Notable examples are the decision to abandon the Compton diode for AURORA application and efforts to continue to develop a high-impedance voltage measurement method. Also, this test impacted plans for the March test by indicating the need for more shielding around the cathode follower and the need for a better method of measuring the Compton current.

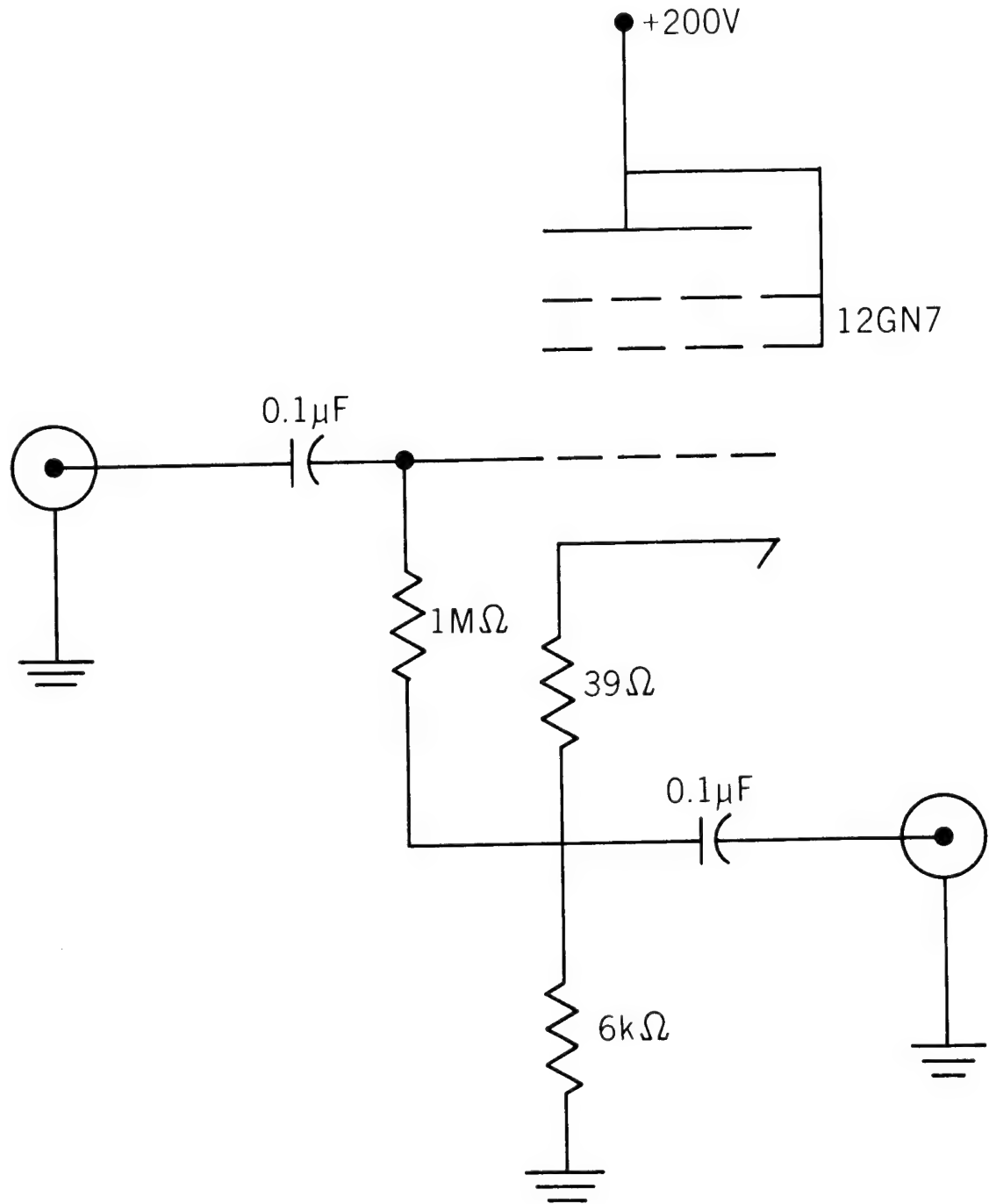


Figure 3. Cathode follower.

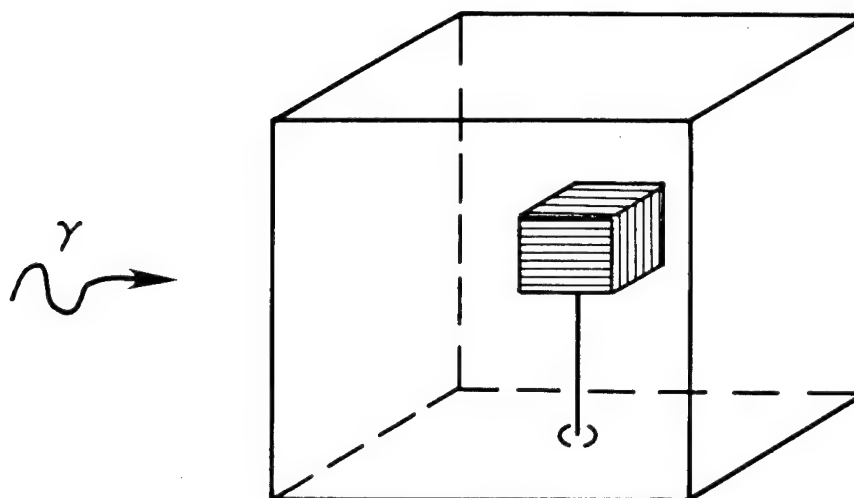


Figure 4. Concentric box test geometry.

## 2.2 March Test

During March and April 1976, a series of tests was conducted at the AURORA Facility to experimentally investigate several matters concerning the electromagnetic environment generated within the tactical source region. These tests provided information within all four general research areas: coupling, instrumentation, basic phenomena, and simulation. In the coupling area, a series of measurements was made to determine current and voltage responses of simple structures exposed to ionizing radiation. In the instrumentation area, data were obtained from instruments designed to measure Compton current, electric (E-) field, and voltage. In the basic phenomena area, air chemistry was addressed by measuring the effect of the charge-depletion boundary layer. Finally, the feasibility of certain simulation schemes was investigated by considering the charging of gamma-thick objects in the radiation environment and the resulting E-field.

The concentric-cylinder geometry in figure 5 was exposed to the AURORA radiation pulse, and the currents and fields in the medium between the cylinders were measured at various locations. Also, the current on the inner cylinder was measured by splitting the cylinder and connecting the sections with parallel resistors, forcing the axial current to be shared by the resistors. The current through one of the resistors was measured and, from that, the total axial current flowing on the inner cylinder could be inferred.

The validity of this inference was demonstrated via laboratory bench tests in which the inner cylinder was driven with a current source as shown in figure 6. The total current was monitored between the pulser and the inner cylinder (location A), and so was the partitioned current flowing in each of the parallel resistors inserted in the inner

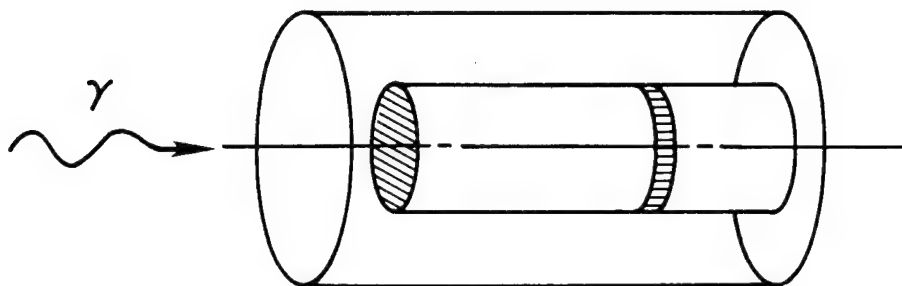


Figure 5. Concentric cylinder test geometry.

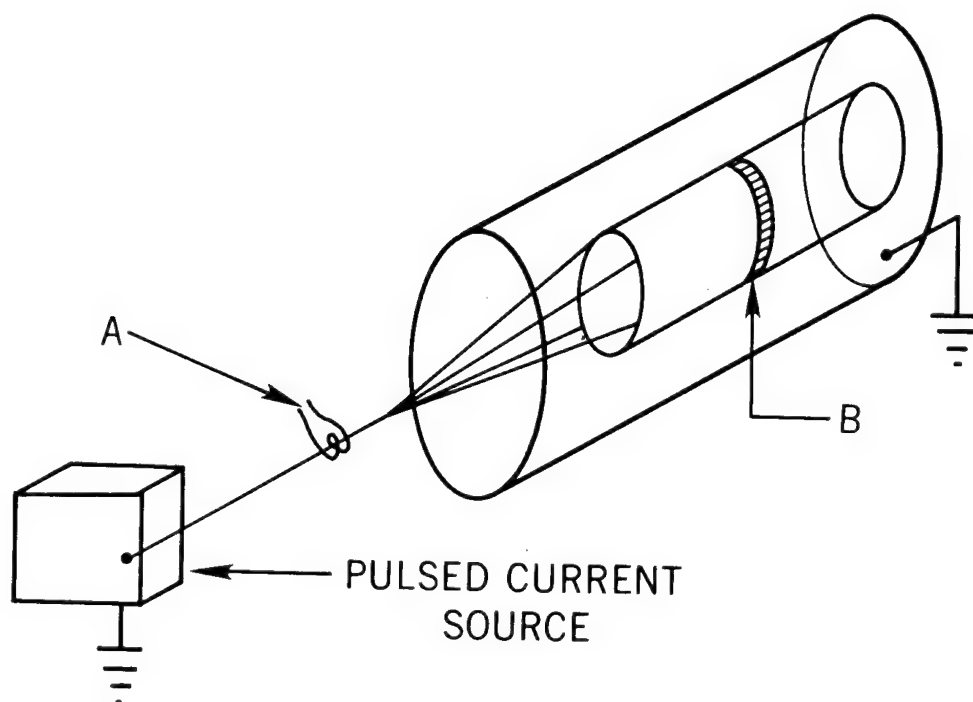


Figure 6. Bench test.

cylinder (location B). Comparison of measurements at locations A and B showed that the total axial current flowing on the inner cylinder was indeed the appropriate multiple of the current measured through one of the resistors.

The concentric-cylinder geometry was selected because it represented a symmetrical configuration within which the fields and currents could be readily calculated everywhere for a symmetrical



excitation. Also, the outer cylinder served as an rf shield against external electromagnetic interference and as a containment vessel for the various media (dry air, N<sub>2</sub> vacuum, SF<sub>6</sub>) under consideration. The data were compared with the calculated response of the inner cylinder obtained by using an assumed radiation distribution as input for the SAPSC computer code.

Several instruments were designed and deployed for this experiment: two one-turn Rogowski coils (to measure Compton current), a cathode follower, a special voltage probe (to make high-impedance voltage measurements), an emitter-follower circuit, and an E-field sensor (used by Denis Whittaker of HDL to measure the E-field).

The one-turn Rogowski coil (fig. 7) consists of a thin aluminum cylindrical outer container with a balanced output located at the center of the axis. The sensor is orientated so that the desired current component passes through the sensor parallel to the axis. The resulting magnetic (H-) field induces a current in the container and results in a voltage developed across the output; this voltage is proportional to the volume of the sensor and the time derivative of the Compton current. For this experiment, two sensors were constructed with volumes of  $5 \times 10^{-2}$  and  $6 \times 10^{-3}$  m<sup>3</sup>.

The cathode follower, which had been used in the December test, was used again, except that considerably more radiation protection was provided in March. It was thought that this extra protection would minimize the transient-radiation effects on electronics (TREE) on the circuit components and that the device would operate as designed. The voltage to be measured was that generated on a Pb pig (a block of Pb), floating coaxially within a large outer cylinder (the same cylinder used for the coupling experiments).

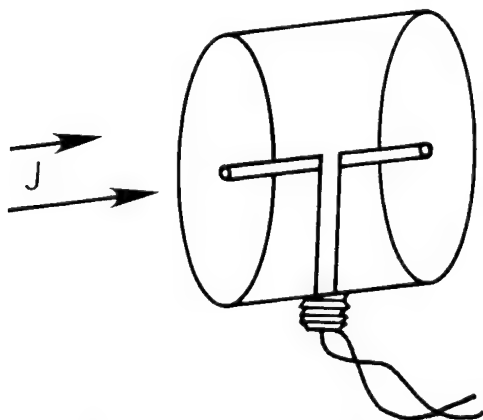


Figure 7. One-turn Rogowski coil (J sensor).

Tektronix voltage probes and specialized compensated voltage divider networks were used to drive the cathode follower, and the response was recorded on oscilloscopes in the data room.

Also, an emitter-follower circuit was used as an impedance matching driver in the same experimental configuration as that with the cathode follower. Further attempts to measure the voltage were made via a method suggested by Victor Van Lint (MRC) whereby a series of short-circuit and low-resistance current measurements was made, and the open-circuit voltage was inferred from the results.

Finally, during successive shots, an E-field sensor was placed at various locations near the floating pig, and the measured E-field was recorded. From these measurements, the total E-field, as a function of distance from the floating pig, could be determined and, from that, the voltage.

The third area of investigation concerns the basic phenomena and air chemistry associated with the source-region environment. For some time, certain air-chemistry parameters have been somewhat inadequately determined. Notable is the electron attachment rate in moist air. Data from a variety of investigations and compiled by Longley and Longmire\* indicate that there is a major fluctuation in this parameter over the range of fields and pressures of interest for EMP. By these data, though, the measurements of electromagnetic environments resulting from nuclear tests do not agree well with the corresponding calculations (Conrad L. Longmire, MRC, private communication).

Consequently, it is desirable to obtain controlled experimental data from which the attachment rate can be reliably derived. To get these data, a "pie-pan" sensor was designed in collaboration with Longmire. The basic design (fig. 8) consists of a thin center plate which can be charged with an external power supply and capacitor network. The current discharged by the capacitor can be related to the phenomena which occur between the plates of the sensor when it is exposed to ionizing radiation. Attachment rates, recombination rates, conductivity, and the charge-depletion boundary layer can be studied in various gases by using this experimental setup. For this series of tests, two sensors were constructed, one with a plate separation of 2.54 cm and one with a plate separation of 5.08 cm.

Although all of the experiments conducted during this test series had some relation to tactical source-region simulation, the floating pig experiments provided direct insight into one of the field enhancement methods under active consideration. Gamma radiation and Compton currents build up the charge on conducting bodies which are thick to the incident ionizing radiation. This charge buildup results in an E-field which, perhaps, could be appropriately tailored to complement E-fields due to other mechanisms in a reasonable simulation of worst-case environments.

In the context of a long-term program, the March test was not meant to stand alone, but rather was designed to clear up some previous uncertainties and to begin investigation into some new areas. Examples are the current measurements on the truncated cylinder and the boundary-layer oriented pie-pan measurements. In general, the results of the March test contributed to a variety of areas.

---

\*H. J. Longley and C. Longmire, *Electron Mobility and Attachment Rate in Moist Air*, Mission Research Corp. MRC-N-222 (12 December 1975).

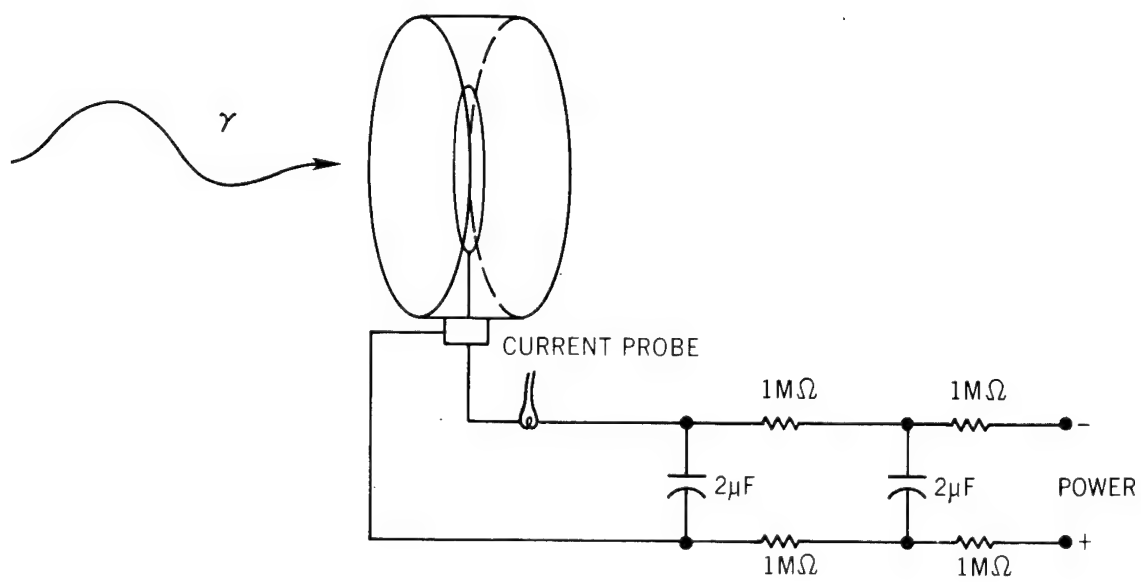


Figure 8. Pie-pan sensor.

### 2.3 Mission Research Corp./AURORA Memorandums

Conrad Longmire and William Crevier of MRC wrote four AURORA Memorandums in FY76: General Considerations on the Use of AURORA for Simulating EMP Coupling, Some Physics Experiments for AURORA, A Simple Analysis of the Blue Cylinder Experiment, and AURORA Boundary Layer Experiments. These AURORA Memorandums, along with Direct Interaction Effects in EMP,<sup>2</sup> form a collection of material that is a great help in understanding the possible uses of the AURORA Facility in source-region coupling experiments related to tactical situations of interest. Figure 9 shows an early example of a relatively simple AURORA modification, suggested by Longmire, that would convert the AURORA Facility into a partial simulator of the tactical source-region EMP. Longmire's modification would not provide an exact simulation of source-region EMP, but many of the important electromagnetic features of the source region would be partially simulated.

### 2.4 Code Development Contracts

Early in FY76, a contract was let to Science Applications, Inc. (SAI), to develop two computer codes and to provide the Government with a user's manual for these codes. Both of these codes solve Maxwell's

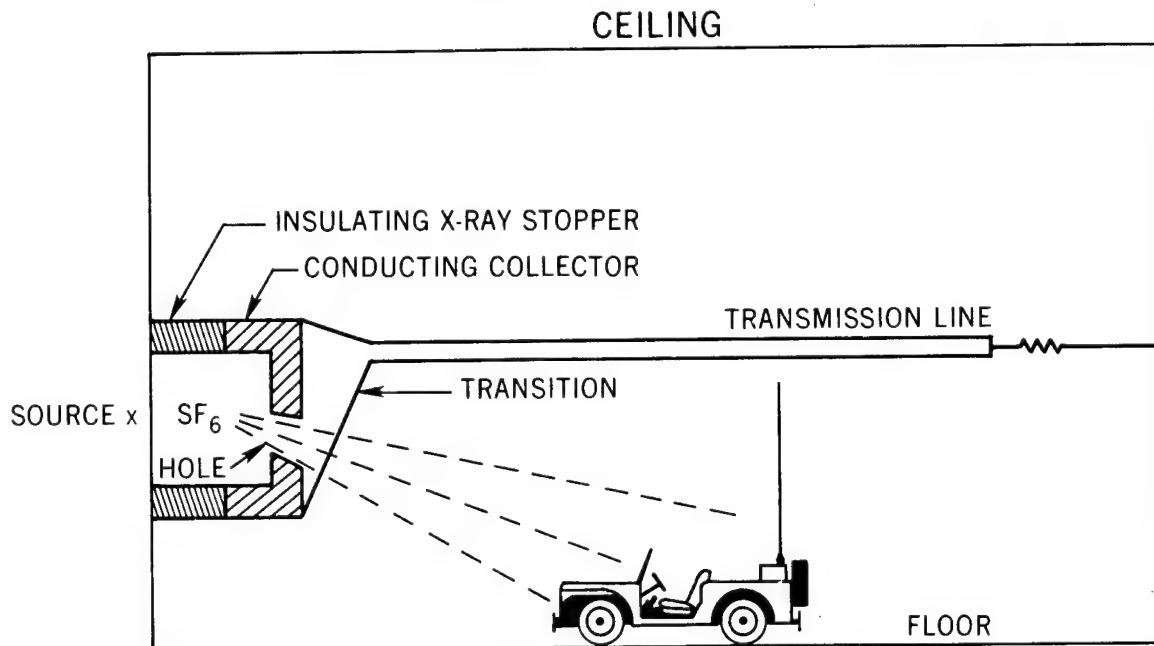


Figure 9. Possible simulation scheme.

<sup>2</sup>C. L. Longmire, *Direct Interaction Effect in EMP*, Air Force Weapons Laboratory, EMP Interaction Note 69 (November 1973).

equations in cylindrical coordinates, and both can analyze concentric cylinder geometries irradiated at the AURORA Facility. These codes provide the following types of output: electromagnetic fields, conductivities, and Compton currents in the region between the cylinders and the current coupled to the inner cylinder or the voltage generated between the outer cylinder and an electrically isolated inner body.

One of the codes uses a standard explicit finite-difference scheme to solve Maxwell's equations. It can treat the source electrons either self-consistently or non-self-consistently, allowing one to determine whether or not a self-consistent treatment is necessary for the analysis of AURORA experimental results. In addition, the self-consistent treatment will allow the code to operate for actual tactical source-region EMP environments if the effects of low-energy electrons can be neglected.

The other code uses an implicit finite difference scheme to solve Maxwell's equations. It can treat standard concentric cylinder geometries, and, in addition, configurations in which the cylinders are connected by lumped circuit elements (resistance, inductance, capacitance).

In addition to the computer codes, SAI will provide the results of four sample problems of HDL's choosing with the electron transport calculations used for each.

During FY76, work on the Maxwell equation equivalent circuit (MEEC) code progressed under contract with Intelcom Rad Tech (IRT), technically directed by Thomas Tumolillo of JAYCOR. The code is being developed for simulation studies and solves the Maxwell equations in rectangular Cartesian coordinates (by finite difference techniques) in a volume of air (or other gas) excited by Compton electrons in the presence of associated time-varying air conductivity.

The MEEC code is in the final phase of programming and debugging; that is, modification of the vacuum system generated EMP (SGEMP) version of the MEEC code to handle source-region effects of an ionized gas (typically air) is essentially complete. A flexible input language has been defined and coded in FORTRAN. The input language allows convenient access to all essential parameters entering the calculations. The coding associated with the calculation of air conductivity and the self-consistent tracking of source electrons (one available option) is complete. It is anticipated that the complexity of the entire modification of the MEEC code will require extensive and thorough testing and evaluation. In FY77, available AURORA experimental data will be compared with MEEC calculations.

## 2.5 Environment Code NEMP

The Army has sponsored the development of the NEMP computer code system, principally by Longley and Longmire, for prediction of EMP environments due to near-surface air bursts. After several years of effort, the code system (consisting of six codes run in sequence) is in a limited production status. The code system has been run to times of 5 ms by personnel of HDL using a rough EMP source package for a 200-m height of burst. Some further work will be done by MRC in FY77 to verify the correctness of the computed fields and to examine fields extrapolated outside the source region.

The Army has sponsored also Monte Carlo transport studies by M. O. Cohen of the Mathematical Applications Group, Inc. (MAGI), to obtain predictions of EMP sources due to neutron-induced secondary gamma rays for burst heights of 50 and 100 m. These predictions are of a higher quality than heretofore available, especially near the air-ground interface. Additional studies by MAGI of more general neutron spectra are planned for FY77.

Meanwhile, HDL is developing a NEMP output graphics code and is performing analytic curve fitting of the MAGI transport results for inclusion in the NEMP code system. Also, HDL has brought the NEMP system to a production status on the HDL computer, an IBM 370/168 system, in addition to the Control Data Corp. (CDC) 7600 system on which the NEMP code was developed.

## 2.6 Interaction and Coupling Analyses of Lance Missile System and AN/GRC-106 Radio System

The EMP survivability criteria for tactical endoatmospheric nuclear threats differ significantly from those for exoatmospheric threats because of several factors:

a. The presence of ionizing radiation, Compton current density, and time-varying conductivity for endoatmospheric threats

b. The "near-zone" character of the electromagnetic field for endoatmospheric threats as opposed to the radiated plane wave character for exoatmospheric threats

c. Relatively large field strengths of certain components at times beyond 1  $\mu$ s or so for endoatmospheric threats.

Furthermore, from preliminary analyses of isolated interaction and coupling mechanisms, it can be argued that these differences between EMP survivability criteria for exoatmospheric and tactical endoatmospheric nuclear threats can lead to significantly different interaction and coupling phenomena.

Going one step further, some voids can be identified in the existing technology base--that is, technology developed specifically for tactical endoatmospheric threats, technology developed for strategic endoatmospheric threats and applicable also to tactical situations, and technology developed for exoatmospheric threats and easily modified to account for certain "weak" source-region effects. These voids can be identified through vulnerability assessments of actual tactical systems; these assessments are attempted in sufficient detail to illuminate such technology voids. The interaction and coupling analyses of the Lance Missile System and the AN/GRC-106 Radio System were performed, therefore, according to the following approach:

a. Define principal response mechanisms and critical circuits for both systems with respect to the tactical source-region environmental factors listed in the first paragraph of this section.

b. Develop worst-case idealized representations of principal response mechanisms, and define the state-of-the-art theoretical methods which can be applied with the most confidence in the system analyses.

c. Predict responses of principal interaction and coupling mechanisms and the corresponding source impedances which are necessary to assess susceptibilities of critical circuits to damage.

d. Develop techniques and design tests which will provide experimental verification of these theoretical predictions; consider underground nuclear tests, flash x-ray machines, electron-beam machines, and current injectors.

e. Identify voids in existing theoretical and experimental technology which seriously impede meaningful susceptibility and vulnerability assessments.

The interaction and coupling analyses of the Lance Missile System and the AN/GRC-106 Radio System were conducted under an Army-sponsored contract.<sup>3,4</sup> Four types of excitation of each system were considered:

a. Electromagnetic excitation (electromagnetic field and transient air conductivity) of external cables and antennas

b. photon excitation of external cables

---

<sup>3</sup>R. A. Perala et al, *Coupling Calculations for the LANCE Missile System in a Tactical Nuclear Environment (U)*, Mission Research Corp. Report No. AMRC-IR-76457 (March 1976). (SECRET RESTRICTED DATA).

<sup>4</sup>R. A. Perala et al, *Close-in Coupling Analysis of the AN/GRC-106 Radio System (U)*, Mission Research Corp. Report No. AMRC-IR-76458 (March 1976). (SECRET)

c. Electromagnetic excitation of internal cables due to internal EMP (IEMP)

d. Electromagnetic excitation of internal cables due to apertures in enclosures

The contractor's results from the interaction and coupling analyses of the Lance Missile System and the AN/GRC-106 Radio System have been used at HDL to assess the susceptibility of critical circuits to damage.<sup>5</sup>

### 3. TECHNICAL MILESTONES

Throughout FY76, technical efforts were directed toward specific goals outlined in section 1. Significant progress has been made and, as a result, some definitive statements can be made in several technical areas. These areas include boundary-layer phenomena, Compton current measurements, E-field measurements, voltage measurements, and gamma-thick charging phenomena.

This section does not completely describe all of the technical work undertaken during FY76, but discusses only those topics about which some conclusions or significant results have been obtained.

#### 3.1 Boundary-Layer Conclusions and Results

Longmire<sup>2</sup> and Baum<sup>6</sup> considered the development of an electron depletion layer between a negatively charged conductor and a collision dominated plasma. As shown in figure 10, when a metallic electric conductor is negatively charged, the resulting E-field is in a direction to remove electrons from the metal surface; however, no electrons are removed from the metal surface. Electrons cannot be emitted because the E-field ("E" in fig. 10) is not large enough to produce high-field emission, a phenomenon that occurs only at extremely high E-field intensities. To be specific, experimentally it has been found and theoretically it may be shown that the high-field emission current density,  $J_{hf}$ , is given by

$$J_{hf} = CE^2 \exp(-K/E) ,$$

---

<sup>2</sup>C. L. Longmire, *Direct Interaction Effect in EMP*, Air Force Weapons Laboratory, EMP Interaction Note 69 (November 1973).

<sup>5</sup>Daniel L. Goodwin, *The LANCE Electromagnetic Pulse (EMP) Assessment--Endoatmospheric Threat (U)*, Harry Diamond Laboratories TM-77-14 (October 1977). (CONFIDENTIAL)

<sup>6</sup>C. E. Baum, *Radiation and Conductivity Constraints on the Design of a Dipole Electric Field Sensor*, Air Force Weapons Laboratory EMP Sensor and Simulation Note 15 (June 1970).



where, for a tungsten emitter, the constants C and K are given by

$$C = 1.26 \times 10^5 \text{ A/V}^2 ,$$

$$K = 2.76 \times 10^{10} \text{ V/m} .$$

At  $10^6 \text{ V/m}$ ,

$$J_{hf} = 1.26 \times 10^5 \times 10^{12} \exp(-2.76 \times 10^4) \quad (1)$$

$$\approx 0 .$$

The foregoing equation holds only for perfectly clean flat surfaces. Microscopic irregularities can cause extremely high local E-fields which can sometimes cause enough current to produce local hot spots. Thermionic emission can then occur. One of the reasons for conducting the pie-pan experiments is to see if electron emission does or does not occur by some such mechanism. If electron emission does not occur, a region of positive ions results. As indicated in figure 10, a rather intense E-field connects these positive ions with the electrons in the metal.

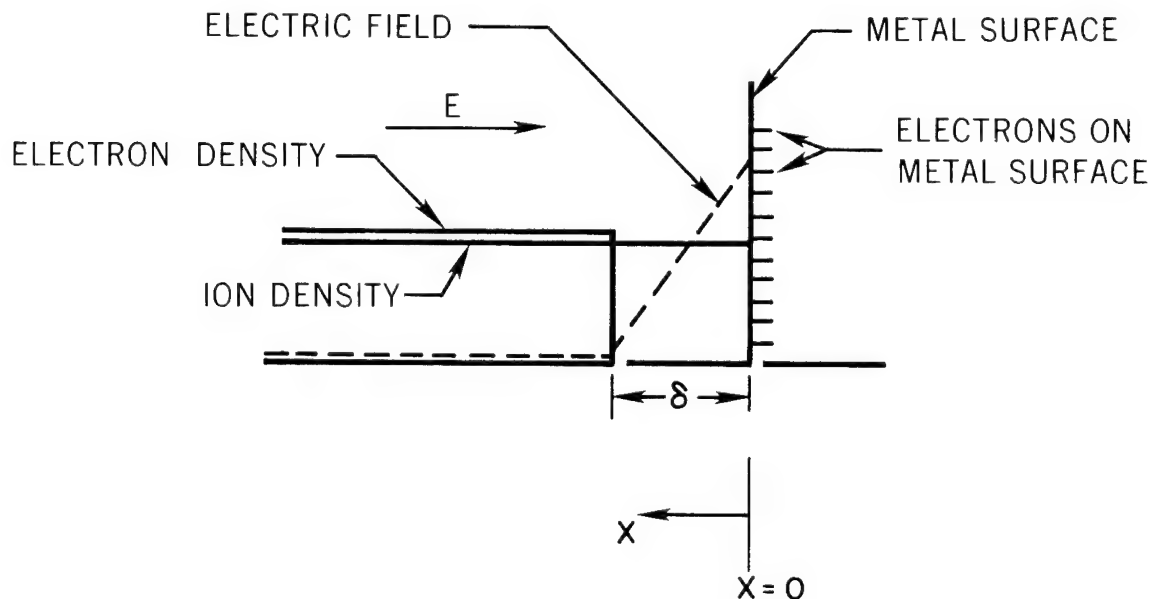


Figure 10. Model of boundary layer.

Consider the situation when the sensor shown in figure 11 is filled with  $N_2$  gas and subjected to an AURORA radiation pulse. If one neglects the boundary layer and applies conventional wisdom, current should flow through the chamber as long as the  $N_2$  gas remains ionized. By using accepted electron-positive  $N_2$  ion recombination rates, the  $N_2$  gas should remain ionized much longer (milliseconds) than the duration of the AURORA pulse (300 ns).

When the chamber was subjected to the AURORA ionizing radiation pulse, current flowed through the chamber only for a time approximately equal to the duration of the AURORA pulse. The short duration of the current pulse is consistent with the formation of an electron depletion region or boundary layer at the center of the negatively charged electrode. If there were no boundary layer formed at the inner conductor, current would flow for times up to milliseconds, that is, until all the electrons recombined with the positive nitrogen ions.

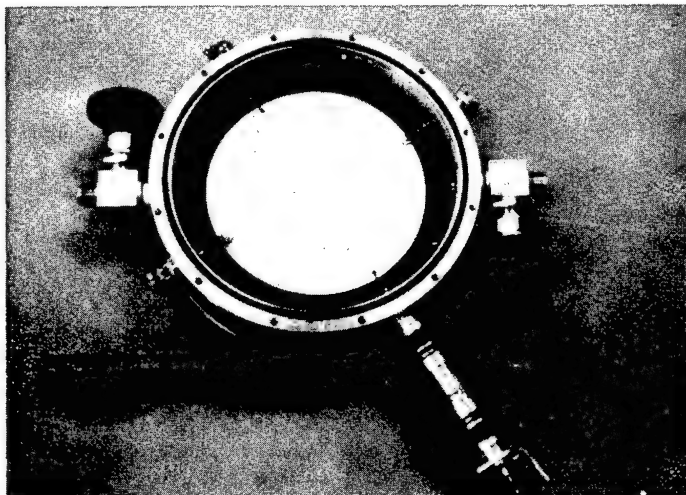


Figure 11. Pie-pan sensor.

Crevier and Longmire (MRC, unpublished data) have developed a quantitative theory to explain the behavior of the sensor when subjected to the AURORA pulse. Essentially, the current that flows through the sensor is set equal to

$$\dot{q} = i(t) = \sigma(t)E(t)A, \quad (2)$$

where  $i(t)$  is the current,  $\sigma(t)$  is the ionized gas conductivity,  $E(t)$  is the E-field outside of the plasma boundary layer, and  $A$  is the area of the plate. Then

$$\dot{q} = \frac{V_p - V_{bl}}{D} \mu e N_e A = \sigma E A , \quad (3)$$

where  $V_p$  is the voltage across the sensor plates,  $V_{bl}$  is the boundary-layer voltage across the electron depletion layer,  $D$  is the distance between the plates,  $\mu$  is the electron mobility,  $e$  is the electric charge of an electron, and  $N_e$  is the electron number density.

Voltage  $V_{bl}$  is given by the integral of the E-field  $E_{bl}(x)$  across the electron boundary layer:

$$E_{bl} = - \frac{V_p}{D} - 4\pi e N_+ (\delta - x) , \quad (4)$$

where is assumed to be a relatively sharp cutoff of the boundary layer. Then

$$V_b = \int_{\delta}^0 E_{bl}(x) dx . \quad (5)$$

The charge,  $q$ , per unit area on the negatively charged conductor can be set equal to the charge in the boundary layer. Then

$$q = e N_+ \delta A , \quad (6)$$

or

$$\delta = \frac{q}{e N_+} ,$$

and

$$E_{bl} = - \frac{V_p}{D} + 4\pi (e N_+ \delta) \left( \frac{x}{\delta} - 1 \right) ,$$

or

$$E_{bl} = - \frac{V_p}{D} = 4\pi q \left( \frac{x}{\delta} - 1 \right) . \quad (7)$$

Then follows

$$\begin{aligned}
 V_{bl} &= \int_{\delta}^0 E_{bl} dx \\
 &= -V_p \frac{\delta}{D} + 4\pi q \left( \frac{x^2}{2\delta} - x \right) \Big|_{x=\delta}^{x=0} \\
 &= +V_p \frac{\delta}{D} + 2\pi q \delta \\
 &= +V_p \frac{\delta}{D} + \frac{2\pi q^2}{eN_+} .
 \end{aligned} \tag{8}$$

The fraction  $\delta/D$  is much less than 1, so

$$V_{bl} \equiv \frac{2\pi q^2}{eN_+} .$$

Equation (3) then becomes

$$\dot{q} = \frac{\mu e N_e}{D} \left( V_p - \frac{2\pi}{eN_+} q^2 \right) A , \tag{9}$$

where the electron mobility is given by

$$\mu = 7.33 \times 10^5 E^{-1/2}$$

for  $0.1 < E < 10$  electrostatic units. One can insert the proper  $N_2$  gas chemistry to obtain the results shown in figure 12.

The pie-pan sensor has been used to study the conductivity and boundary-layer effects in a number of pure gases and mixtures of gases for E-fields up to 80,000 V/m. The gases studied have been dry air,  $N_2$ ,  $O_2$ ,  $SF_6$ , and, finally, "humid" air with humidities ranging from 0 to 100 percent at 36°C.

When a specific gas was studied at a specific dose level, current pulse measurements corresponded to 2000, 1000, 300, 100, and 10 V applied to the sensor.

The experimental technique used in obtaining the 100-percent saturated humid air (at temperature T) was to bubble dry air through two flasks in series containing water at temperature T. The pipes, hoses,

$N_2$  , AIR (DRY AND WET)  
 $O_2$  ,  $SF_6$   
 $I = AN_e V_e \approx \text{TENS OF AMPERES}$

IN AIR  $N_e = \dot{\gamma} / \alpha_e$

$$V_e = \mu_e E$$

$$I \propto \dot{\gamma} \mu_e / \alpha_e$$

$$E = \frac{V_p - V_{bl}}{D}$$

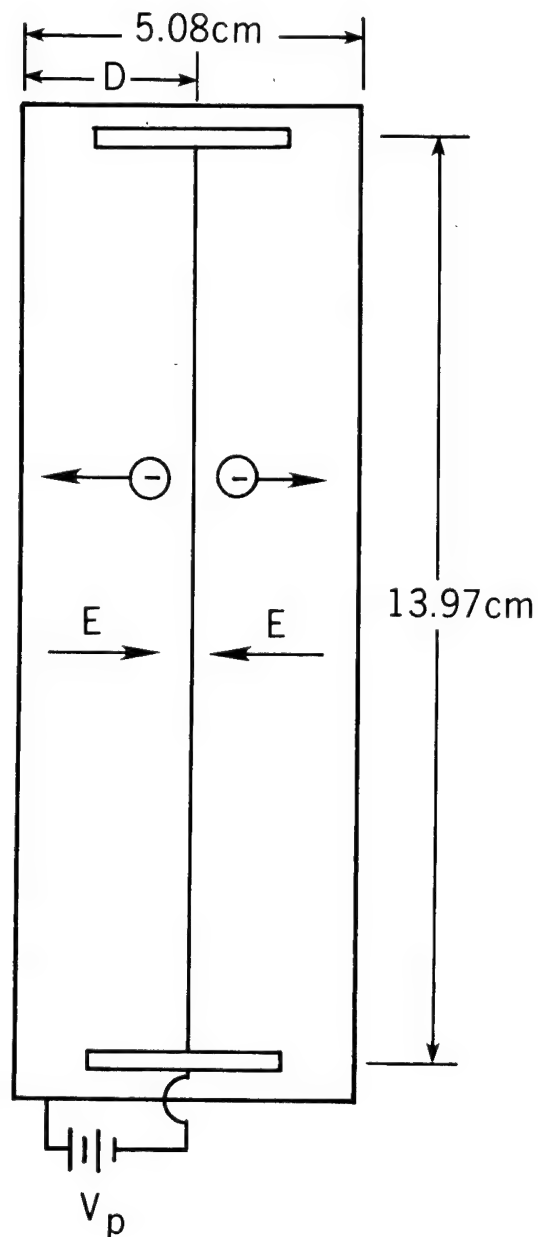


Figure 12. Pie-pan model (used in W. Crevier and C. Longmire calculation, Mission Research Corp.).

and pie pan were kept at a temperature about 5° to 10°C hotter than the water. The setup is depicted in figure 13. Since the sensor was at a temperature greater than T, water did not precipitate in the sensor. Figure 14 shows a schematic drawing of the experimental setup during an AURORA shot.

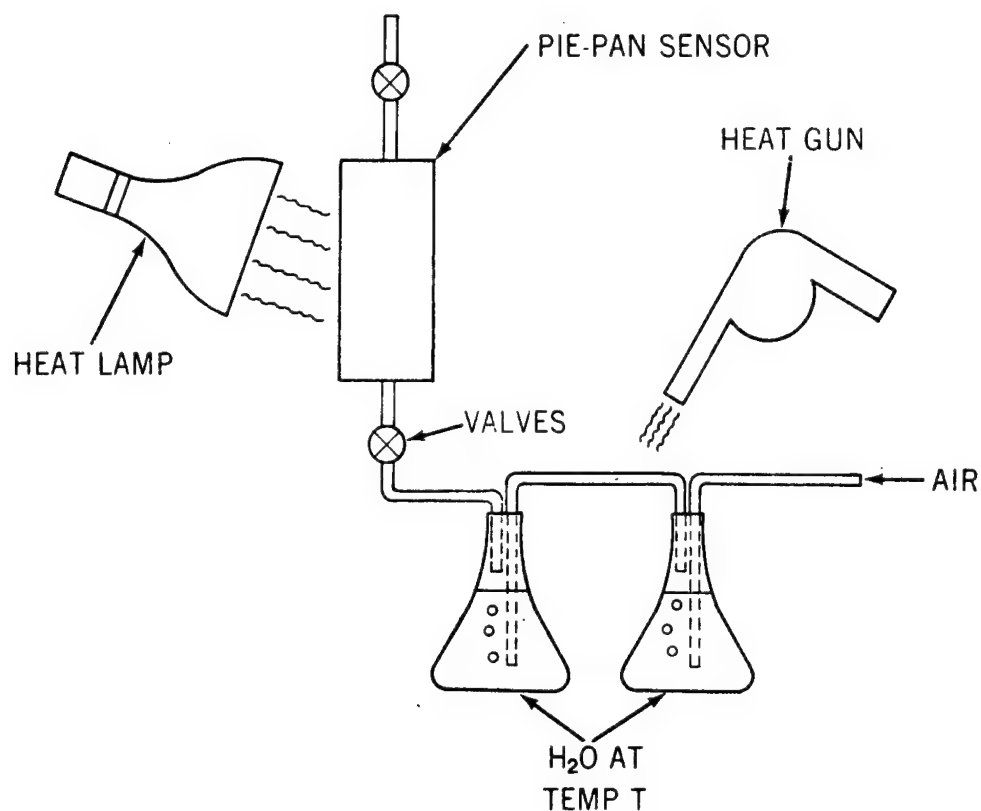


Figure 13. Method of filling pie-pan sensor with humid air.

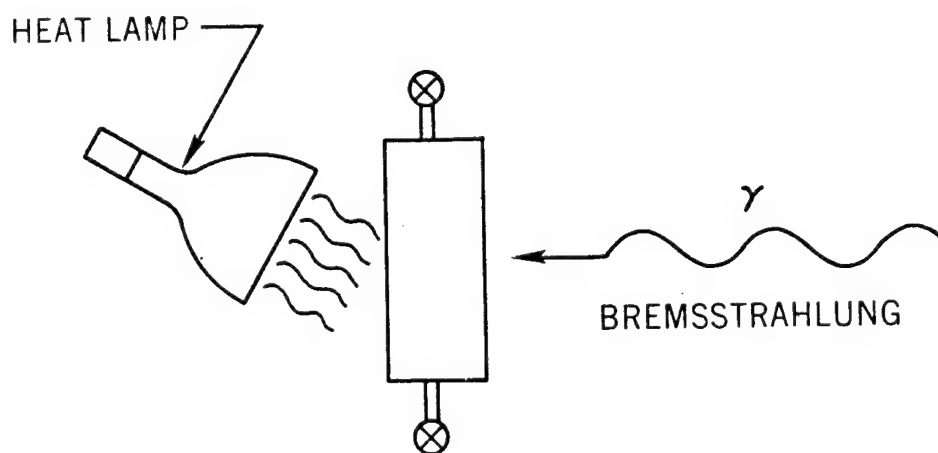


Figure 14. Method of preventing  $H_2O$  precipitation if humid air is 100-percent saturated at temperature  $T$  and sensor is heated to temperature  $T_s$ , where  $T_s \geq T + 5^\circ C$ .

The dry-air and  $N_2$  experimental data have been reduced, and sample comparisons between the theoretical responses and the measured data are given in figure 15. The  $O_2$ ,  $SF_6$ , and humid-air data have not yet been corrected for cable losses, etc. However, the conductivity of the 100-percent humid air at  $50^\circ C$  is about 4.5 times less than that of dry air.

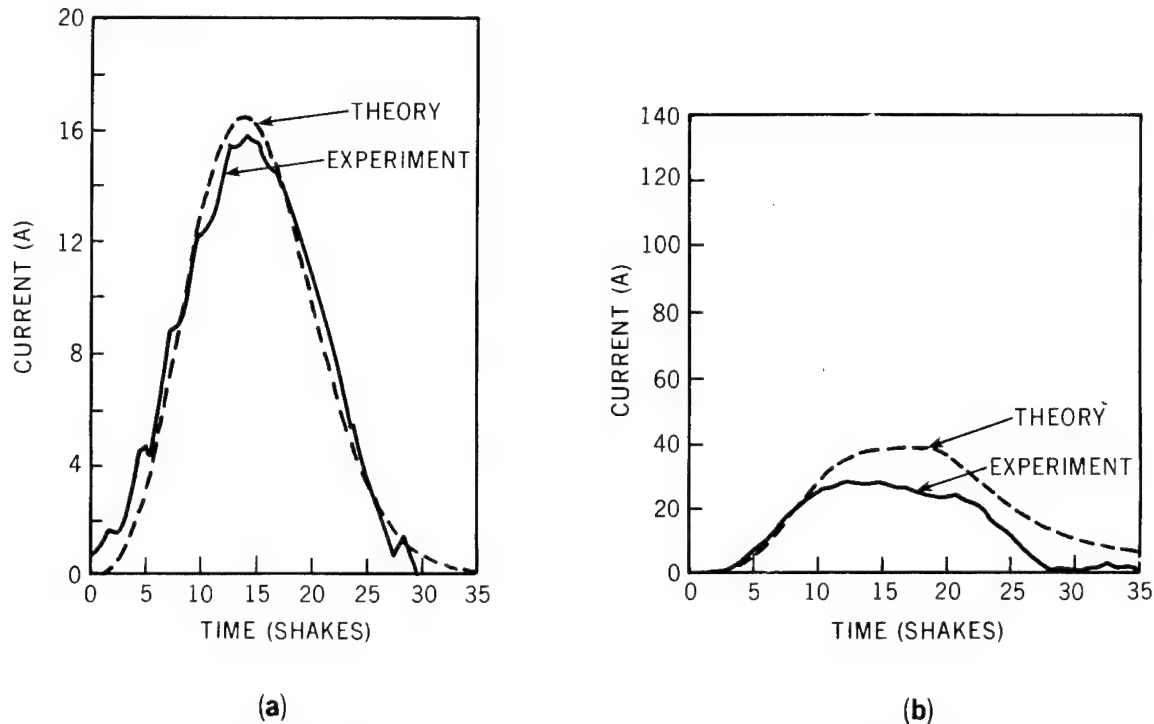


Figure 15. Pie-pan response: (a) dry air and (b) nitrogen (bias: 1000 V).

### 3.2 Compton Current Measurement

One of the stated goals of the FY76 experimental effort was to measure the "free" electromagnetic environment in the AURORA test cell during the radiation pulse. One important parameter to be considered was the Compton current. Several different instruments were considered, and data were obtained by using each. These included the Compton diode (which has been used extensively for underground tests), the Rogowski coil type of current probe (both in a special collimated configuration and as an off-the-shelf item), and the one-turn Rogowski coil. Measurements were made during the December and March AURORA tests, and the significant results were compiled for all of the data.

The Compton diode, although it has been demonstrated to be a powerful experimental tool, has two inherent problems. One is that, to be sensitive to small current densities, it must be large. Another is

that it collects current indiscriminately and must be collimated and shielded if one is to determine the vector current density at any location. These two problems act in opposition. Experience during FY76 indicated that these problems would be extremely difficult to solve. The Compton diode with which data were taken was designed so that a reasonable signal should be obtained while size and shielding were kept to a minimum. The reason for this size restriction was that once a reliable means of measuring Compton current was determined, the AURORA test cell would be mapped. The sensor, therefore, had to be small and portable to map the test cell. The initial data obtained by using the sensor showed signals which were buried in the noise. Attempts to increase the sensitivity of the sensor by changing the resistance divider in the output failed to produce reasonable results. The total dose on the front of the sensor (measured by using TLD's) indicated that adequate Compton current should be reaching the sensor, but the cable noise level was such that meaningful results could not be obtained. Consequently, either (1) considerable effort would have to be undertaken to increase the sensitivity or reduce the noise or (2) the general approach could be abandoned for the time being in favor of pursuing other concepts. The latter pursuit was chosen.

The Compton current was measured also by using ADELCO current probes of 4.3-cm diameter. Reasonable measurements of the Compton current could be made inside the concentric cylinder geometry (where the probe was afforded considerable rf shielding), but in the AURORA test cell itself, results were inconsistent. As with the Compton diode, collimation is required to measure one vector component of the current density at a location. When the collimator was used during the December test, the signal was reduced to the level that noise problems were overwhelming. When the collimator was removed during the December test, however, the measurements were within 20 percent of the predicted values. Unfortunately, the measured values were neither consistently greater nor less than the predicted values, and during the March test there was little correlation between the theoretical and the experimental values. This lack of correlation may be due to the fact that the ADELCO probes measure the total current (not just the Compton current) passing through them, and the Compton current could not be separated from the conduction current. Enclosing the current probe with an aluminum can filled with SF<sub>6</sub> would prevent conduction current from passing through the current probe and might allow a successful Compton current measurement with this type of probe. Also, varying the thickness of the can could provide information concerning the energy spectrum of the electrons produced in the AURORA test cell. During the March test, a larger ADELCO probe (13.3-cm diameter) was used, but measurements were not successful more than 2 m from the hot spot.

Longmire suggested (unpublished) the one-turn Rogowski coil as a means of measuring the Compton current. Further refinements in the



original design resulted in a sensor that measured the Compton current with no requirement for collimation. In addition, the differential output minimized the noise problems. Two models of the sensor were constructed and used during the March test. Data were taken by using the small sensor over a range of dose rates from  $10^9$  to  $10^{11}$  rads (Si)/s, but the sensor response was not as predicted. Careful consideration of the data indicated that the sensor was not sensitive enough, considering the noise levels, for AURORA application. The larger sensor provided reasonable results over that dose rate range. Peak amplitudes of the integrated reduced data compared favorably with the predicted peak Compton current density of  $J = -2 \times 10^{-8} \dot{R} \text{ A/m}^2$ , where  $\dot{R}$  is the dose rate in rads (Si)/second (fig. 16). Comparison of the integrated pulse shape with the AURORA radiation pulse (appropriately scaled) (fig. 17) is similarly good. The discrepancies between the measured and predicted data seem to be most prominent in the lower radiation region indicating that  $10^9$  rads (Si)/s is probably the lower limit of the response range of the sensor. Since the response of the sensor is proportional to its volume, use of a larger sensor should extend the range over which measurements can be valid.

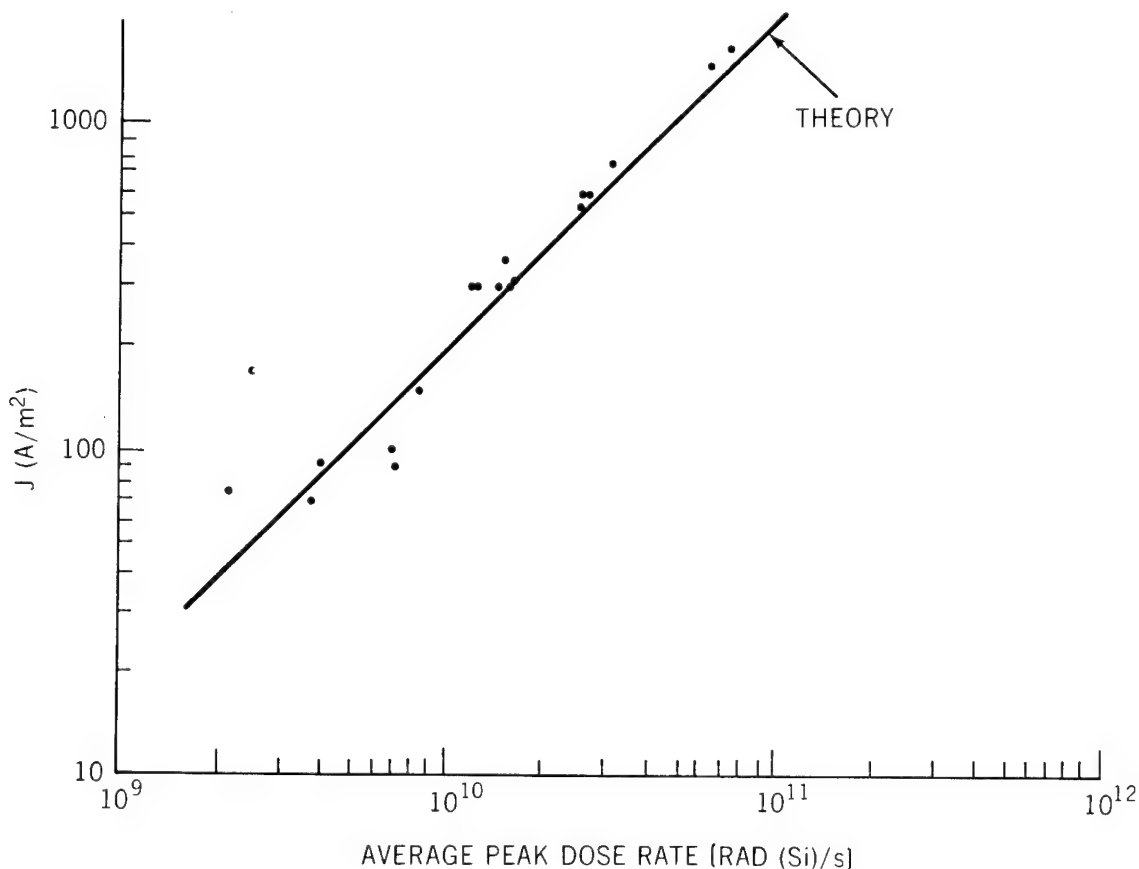


Figure 16.  $\dot{J}$  sensor.

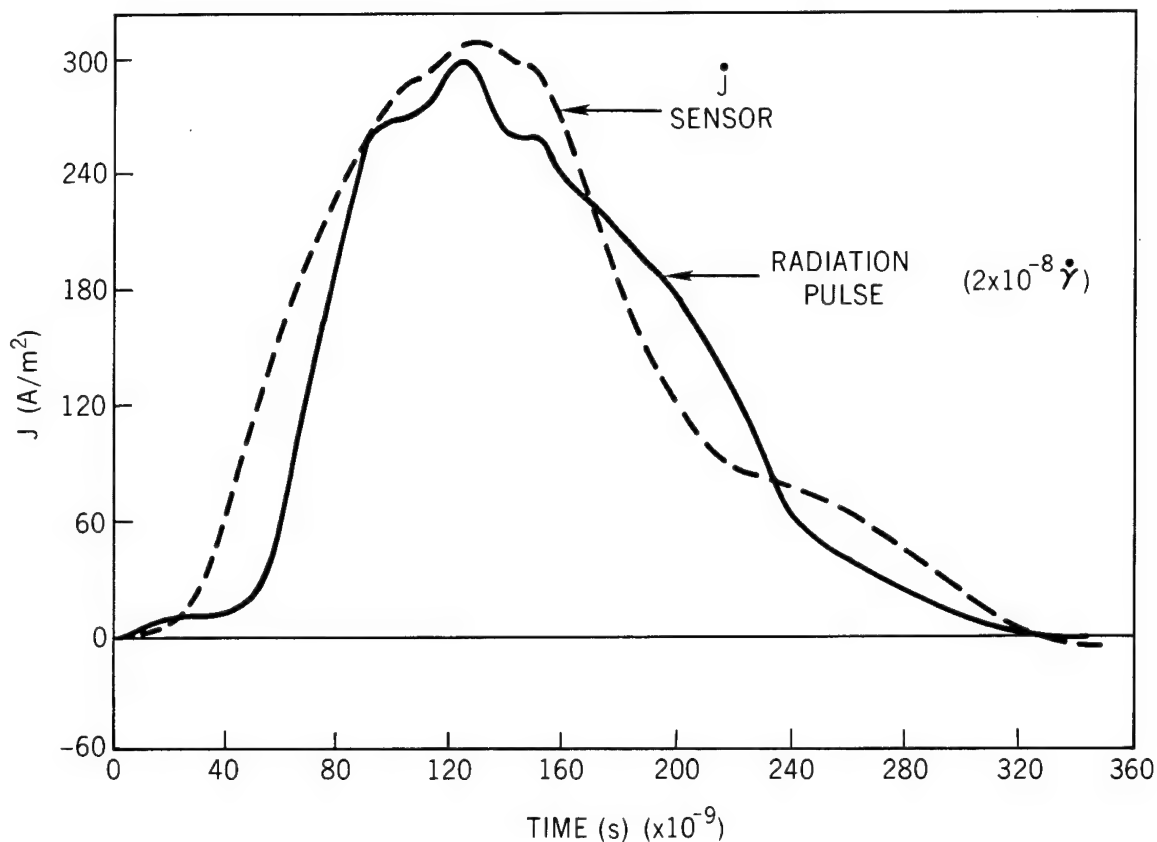


Figure 17. Compton-current time history.

In conclusion, use of the one-turn Rogowski coil sensor seems the most adequate method of measuring the Compton current in the AURORA test cell. In the future, a larger, more sensitive model will be constructed. By its use, the Compton current spacial distribution within the AURORA test cell can be fully characterized.

### 3.3 Electric-Field Sensor

The measurement of the E-field in a medium that has a time-varying conductivity, such as the ionized air present in the AURORA test cell, has proved to be difficult. Consider a parallel plate sensor (with plates separated a distance  $d$ ) that is placed with the plates perpendicular to the E-field (fig. 18). Let the load across the plates be resistance  $R$ . Conservation of current then yields

$$\epsilon_0 \frac{dE}{dt} = \epsilon_0 E' + \epsilon_0 \frac{dE'}{dt} + \frac{AE'd}{R}, \quad (12)$$

or in terms of the voltage,  $V$ , across  $R$ , assuming that the value of  $E$  is not changed by the presence of the sensor,

$$A\sigma E - A\epsilon_0 \frac{dE}{dt} = \frac{A\sigma V}{d} + \frac{A\epsilon_0}{d} \frac{dV}{dt} + \frac{VA}{R} \quad (13)$$

or

$$-\frac{dE}{dt} + \frac{\sigma(t)}{\epsilon_0} E = \frac{\sigma(t)}{\epsilon_0 d} V + \frac{1}{d} \frac{dV}{dt} + \frac{V}{A\epsilon_0 R} . \quad (14)$$

The solution of this differential equation is given by

$$E = \exp \left[ \int_0^t \frac{\sigma(t')}{\epsilon_0} dt' \right] \cdot \int_0^t (A \cdot B) dt' , \quad (15)$$

where

$$A = \exp \left[ \int_0^{t'} \frac{\sigma(t'')}{\epsilon_0} dt'' \right] ,$$

$$B = \frac{1}{d} \frac{dV}{dt'} + \frac{\sigma(t')}{\epsilon_0} \frac{V}{d} + \frac{1}{A\epsilon_0 R} V(t') .$$

This is a rather unwieldy expression and, unfortunately, it is difficult to simplify under AURORA conditions. Specifically, the AURORA has a rise time of  $10^{-7}$  s, but  $\epsilon_0/\sigma = 10^{-11}/10^{-4} = 10^{-7}$  s, and so both  $dV/dt$  and  $V$  significantly contribute to the determination of  $E$ .

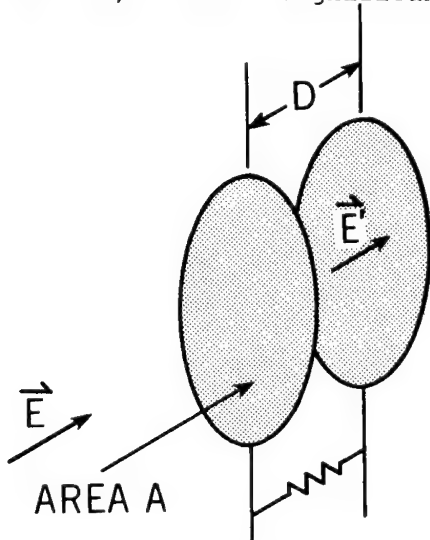


Figure 18. Electric-field sensor.

Furthermore, if a boundary layer or electron depletion layer forms between the ionized air and the negative plate of the sensor, equations (12) and (15) can be oversimplifications. If  $R$  can be made large enough by use of a high input impedance cathode or emitter follower, the plates of the E-field sensor could not collect charge, and the boundary layer phenomena would be kept to a minimum.

Up to the present, a great deal of the work done on E-field measurement in the presence of ionizing radiation has been devoted to situations involving soft x rays. Workers have gone to great efforts to reduce the photoelectric inter-

action between the E-sensor plates and the ambient ionizing radiation. To reduce the possibility of electron emission by the photoelectric effect or by the Compton effect, screens have been substituted for solid plates. To even further reduce the photoelectric electron emission, the screens have been constructed of light, low-atomic-number materials.

The substitution of screens for plates does certainly reduce direct electron knockout by low-energy bremsstrahlung or x rays, but the small area of the screen plates creates another severe problem by enhancing the boundary layer. The boundary layer is enhanced by screens or grids because large E-fields can build up around the small wire or sharp corners of the grid plate.

To be more specific, it can be argued that the voltage across the boundary layer varies as

$$V_b = 1/(\text{surface area})^2, \quad (16)$$

where the surface area refers to the actual electrically dense area of the grid. Grids, therefore, may increase the boundary layer problem. Thin aluminum or copper solid foils may, therefore, have an advantage over grids in constructing the E-field sensor for the AURORA environment. Fortunately, the AURORA bremsstrahlung spectrum is relatively hard, and emission of photoelectrons from the parallel plates may not be important.

### 3.4 High-Impedance Voltage Measurements

It was recognized early in the program that a successful method of making a high-impedance voltage measurement in the AURORA radiation environment would have wide application to include E-field measurements, coupling measurements, and system response measurements. Initial investigation showed that simple resistance divider networks were plagued by two problems: the requirement for capacitive compensation and loss of signal amplitude. These problems exist in proportion to the impedance over which one attempts to measure; the higher the impedance, the greater the signal loss and requirement for compensation. It was indicated that these problems could be greatly reduced by using a cathode follower circuit network, which has a gain of somewhat near unity, but can match high-impedance loads to low-impedance cables. Cathode-follower circuits, rather than emitter-follower circuits, were initially chosen because tubes are generally thought to be less troubled by ionizing radiation than are solid-state components.<sup>7</sup>

During the experiments at AURORA during FY76, high-impedance voltage measurements were made by using cathode followers: one method

---

<sup>7</sup>P. A. Trimmer, *Transient Radiation Effects on Basic Triode Amplifiers*, Harry Diamond Laboratories TR-1197 (April 1964).

used a Tektronix voltage probe, and a second method used a breadboard compensated voltage divider network.

#### 3.4.1 Method 1

A cathode-follower circuit (1-M $\Omega$  input impedance) served as an interface between a Tektronix P6003 voltage probe and a 75- $\Omega$  data cable. A radiation-induced voltage source was sensed by the probe and was recorded from oscilloscopes.

After review of the data, which included several noise measurements, it was concluded that two problem sources prevented successful voltage measurement by method 1: radiation-induced ionization near the tube and radiation interaction with the voltage probe. The ionization near the tube could be minimized by adding more radiation shielding to the circuit. The interaction with the probe could be minimized in the same manner, but more shielding would add considerable stray capacitance, carry the high-voltage signal a great distance, and render the probe inconvenient.

#### 3.4.2 Method 2

Method 2 was similar to method 1, except that the Tektronix voltage probe was replaced with a breadboard compensated voltage probe constructed for this application. As with method 1, the voltage was sensed by the probe and recorded from oscilloscopes.

The failure of method 2 to provide meaningful data was attributed to improper compensation of the voltage probe, due probably to unaccounted-for stray capacitance in the experimental configuration.

Victor van Lint (MRC) indicated that an emitter follower could be designed which could work in the radiation environment. Subsequently, an emitter follower, built to his specification, was constructed, but the results obtained by using it seem inconclusive.

Also, van Lint suggested another measurement method by which the open-circuit voltage can be determined without actually being measured directly. The method requires two current measurements, first with the monitor point short-circuited to ground and then with the monitor point connected to ground through a variety of small resistors. When the peak currents measured are plotted as a function of resistance, the open-circuit voltage can be inferred. This method was tried, but the result was somewhat different from that predicted by Van Lint. The voltage of the gamma-thick body in the experiments may have been influenced by boundary-layer effects so that a determination of the open-circuit voltage would require additional analysis.

Measurements of high-impedance voltage in the AURORA radiation environment remain inconclusive.

### 3.5 Interaction and Coupling Theory

#### 3.5.1 Rectangular Configuration

In the December test, a simple quasi-static model was used to predict (1) the voltage generated between the inner and the outer boxes when they were electrically isolated and (2) the current flowing between the inner and the outer boxes when they were connected by a wire.

For the voltage calculations, the configuration was treated as a capacitor being charged. The total charge flowing between the boxes due to any conductivity in the region between the boxes was subtracted from the total charge deposited on the inner box due to the Compton current. The resultant charge,  $Q$ , was used in the equation  $V = Q/C$  to obtain the voltage generated between the boxes. Since the voltage measurements were unsuccessful, no comparisons between these calculations and actual measurements were possible.

For the current calculations, the current flowing between the boxes was assumed to be due entirely to the Compton current intercepted by the inner box, and electromagnetic effects were neglected. As seen in table I, the results of these calculations reasonably agree with experimental results despite the fact that only direct interaction effects were considered. These calculations are reasonably accurate only because the wire connecting the inner and the outer boxes was perpendicular to the direction of the Compton current flow. If this wire had been in the same direction as the Compton current, the H-field created by the Compton current would have had a significant effect on the coupled current measured. Thus, simple quasi-static models which consider only direct interaction effects may be quite useful in understanding certain interaction and coupling phenomena observed in AURORA experiments.

TABLE I. PEAK COUPLED CURRENT

| $\dot{\gamma}$<br>( $10^9$ rads (Si)/s) | Type  | Experimental<br>current (A) | Theoretical<br>current (A) |
|---|-------|-----------------------------|----------------------------|
| 3.92                                    | Thick | 1.26                        | 1.82                       |
| 3.53                                    | Thick | 1.28                        | 1.63                       |
| 2.92                                    | Thin  | 0.28                        | 0.32                       |

#### 3.5.2 Concentric Cylinders

In the March test, the computer code SAPSC was used to predict the current coupled to the truncated inner cylinder. This code uses a finite-difference scheme to solve Maxwell's field equation in a radiation environment. The Compton source distribution used in the

calculations has a spacial and an angular distribution given by  $(\cos \theta)/R^2$ , where  $\theta$  is the angle between the path of a Compton electron and the axis of the concentric cylinders, and  $R$  is the distance to the center of the AURORA hot spot. The measured data and the output of this code can be compared in figure 19. Theory and experiment disagree somewhat. Two possible improvements in the theoretical treatment are (1) the use of more accurate Compton source distributions and (2) the incorporation of boundary-layer phenomena. The POEM output, which SAI is under contract to deliver to HDL, should provide the former improvement, and work is presently being done on the latter one.

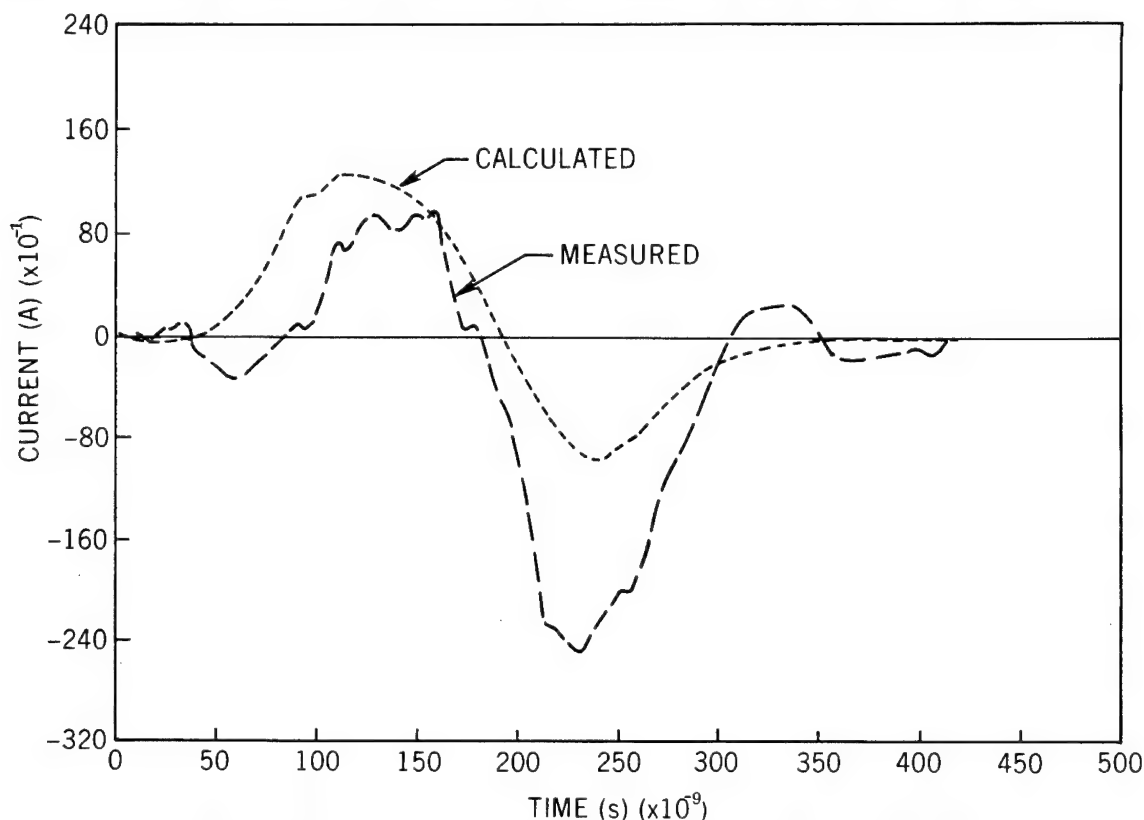


Figure 19. Total axial current on inner cylinder.

### 3.6 Direct versus Electromagnetic Coupling Mode Dominance

The agreement between the crude quasi-static calculation of the current and the measured current in the concentric box experiment may appear trivial. But a calculation that is based on a simple equivalent circuit, neglects inductive couplings, and yields a reasonable answer is useful in the estimation of tactical source region coupling. A purely capacitive quasi-static approach to the estimation of the measured current is valid probably because the wire between the absorber and the wall of the outer cubic chamber is essentially perpendicular to both the Compton current and the H-field resulting from the Compton current.

The amount of magnetic energy in the outer box is appreciable, but the inductive coupling between the inner gamma-thick absorber and the H-field is very small. The magnetic energy in the outer container can be estimated. The inductance per unit length due to the partial flux linkages within a round wire can be shown to be

$$L = \mu_0 / 8\pi , \quad (17)$$

where  $\mu_0$  is the permeability of free space. If the square outer box is approximated with a round box of equal area, the inductance of the Compton current passing through the box is given by

$$L = (\mu_0 / 8\pi) \ell , \quad (18)$$

where  $\ell$  is the length of the box parallel to the Compton current. One can compare the magnitude of the capacitive energy between concentric boxes and the magnetic energy in the outer box. That is,  $\frac{1}{2}CV^2$  can be compared with  $\frac{1}{2}LI^2$ . The Compton current through the box is  $I = JA_0$ , where  $J$  is the Compton current density, and  $A_0$  is the area of the outer box.

The energy found is

$$\frac{1}{2}CV^2 = 2.05 \times 10^{-7} \text{ joules} , \quad (19)$$

and

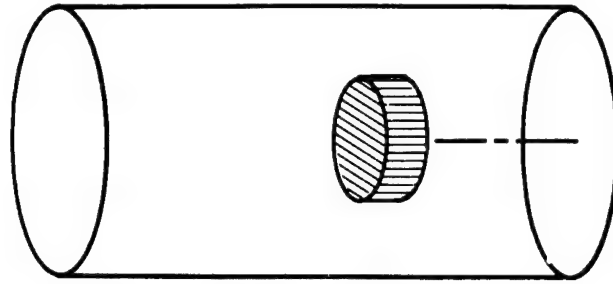
$$\frac{1}{2}LI^2 = 2.50 \times 10^{-6} \text{ joules} . \quad (20)$$

In other words, a significant amount of energy is stored in the H-field, but the energy is not being coupled into the wire between the concentric cubes.

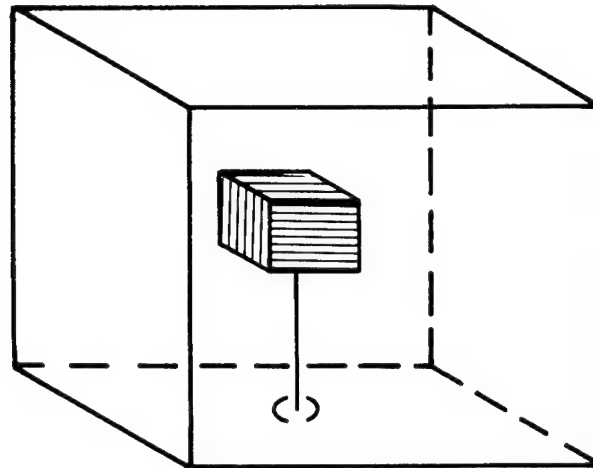
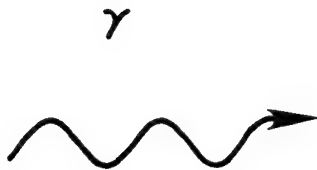
In the March tests, the geometry consisted of a cylindrical gamma-thick absorber inside an outer cylinder. The absorber was connected by wire to the end plate (fig. 20). The resulting current measurements were about 5 to 10 times larger than those calculated with simple quasi-static models that neglect inductance. In this geometry, however, the wire connecting the absorber to the outside container was parallel to the Compton current. Magnetic flux lines encircled this wire; magnetic coupling was indeed possible and important.

Even if inductive and capacitive interactions could be separated only in ideal, experimentally controllable geometries (this limitation is not obvious), then this ability would greatly simplify the design and understanding of experiments. When considering lumped element equivalent circuits of an experimental configuration, it is much simpler to deal with resistors and capacitors rather than with resistors, capacitors, inductors, and transformers. If the lumped





FLOATING PIG



CONCENTRIC BOX

Figure 20. Inductive coupling.

parameters in the equivalent circuit are time varying and nonlinear, the difficulty with the coupling analysis is of even greater significance.

For example, Van Lint has suggested a simple approach to the determination of the voltages of the electrically free-floating gamma-thick absorber: (1) Insert different values of resistance between the gamma-thick absorber and the outer container. (2) Measure the current passing through the resistance between the absorber and the outer chamber when the concentric configuration is subjected to an AURORA pulse. Neglecting inductive effects, one can limit the

equivalent circuit to a current source (the intercepted Compton current) feeding two parallel resistances, (1) the ionized gas,  $R_{\text{gas}}$ , and (2) the inserted resistance,  $R_{\text{in}}$ . In short, van Lint's suggestion can be used without complex computer codes. If the intercepted Compton current is given by  $I_{\text{Compton}}$ , then  $V_{\text{free}} = R_{\text{gas}} I_{\text{Compton}}$  can be measured. It is easy to show by simple circuit theory that the current probe measures

$$I_{\text{probe}} = V_{\text{free}} / (R_{\text{in}} + R_{\text{gas}}). \quad (21)$$

One can measure  $I_{\text{probe}}$  and  $R_{\text{in}}$ . Therefore, a number of measurements should overdetermine  $R_{\text{gas}}$  and  $V_{\text{free}}$ . Actually, since  $R_{\text{gas}}$  is a time-varying function of the E-field, analysis is more complicated, but not as complicated as if one had to consider also magnetic effects.

### 3.7 Data Reduction

The following procedure is used to analyze the data taken during AURORA experiments: The oscilloscope pictures are digitized, and the digitized information is stored on a computer disk file. This information is read into a program which plots the data. The plot is compared with the oscilloscope picture, and any needed corrections are made to the digitized data. The digitized information is then read off the disk file by a computer code (developed at HDL) which (1) numerically transforms the digitized data into the frequency domain, (2) multiplies the frequency domain representation by the appropriate transfer function, (3) transforms this information back into the time domain, (4) multiplies the result by the appropriate sensor response and conversion factors, and (5) plots the resultant information. The plotted information represents the time histories of the actual fields, currents, etc., occurring at the sensor locations during the AURORA tests, not merely measured voltage at the oscilloscope. These plots are then compared with theoretical predictions of test results.

The transfer function used in the computer code is found experimentally. The sensor-cable-balun system used to make a measurement at the AURORA Facility is reassembled at the HDL Woodbridge Research Facility, and its frequency response is measured with a network analyzer to provide the transfer function.

### 3.8 Measurement of Electric Field Produced by Electrically Free Floating Pig

One of the reasons for performing the electrically free floating pig experiments is to investigate the possibility of charging a gamma-thick target and using it to enhance the E-field in a given volume. The behavior of the pig potential also might explain the behavior of a boundary layer as proposed by Longmire.<sup>2</sup> Another reason

<sup>2</sup>C. L. Longmire, *Direct Interaction Effect in EMP*, Air Force Weapons Laboratory, EMP Interaction Note 69 (November 1973).

for performing the series of pig experiments is that, unlike the pie-pan experiment, the potential of the pig is a function of time during and after the AURORA pulse. The potential on the pig and, therefore, on the boundary layer builds up during the first part of the AURORA gamma pulse. If the E-field measurements are being interpreted correctly, the boundary layer collapses after the AURORA pulse ceases. The collapse of the boundary layer in a bremsstrahlung free environment could be interpreted regarding the physics of the boundary layer.

For the measurements described in this report, an  $\dot{E}$  sensor was used. Unfortunately, the results are confusing.

Assuming that the conductivity ( $\sigma$ ) in equation (15) is 0, one obtains

$$\begin{aligned} E &= \int_0^t dt' \left[ \frac{1}{D} \frac{dV}{dt'} + \frac{1}{A\epsilon_0 R} V(t') \right] \\ &= \frac{1}{D} \int_0^t dt' \left[ \frac{dV}{dt'} + \frac{D}{A\epsilon_0 R} V(t') \right] \\ &= \frac{1}{D} \int_0^t dt' \left[ \frac{dV}{dt'} + \frac{V(t')}{CR} \right], \end{aligned} \quad (22)$$

where  $D$  is the distance between the sensor plates and  $E$  is the E-field between the plates. If  $CR > dt$ , one obtains (when the boundary layer can be ignored)

$$\begin{aligned} E &= \frac{1}{D} \int_0^t dt' \frac{dV}{dt'} \\ &= \frac{V}{D}. \end{aligned} \quad (23)$$

To obtain a situation in which  $\sigma = 0$ , a parallel-plate E-field sensor (fig. 21) was put behind a 22.9-cm-thick Pb pig as shown in figure 22. The pig served as a gamma shield. The measurements were carried out with two different gases in the tank, air and  $SF_6$ . The field sensor was positioned at several locations along the axis of the cylinder between the pig and the back wall. The voltage of the pig was determined by integrating the experimentally determined values of the E-field.

Some of the results of the experimental measurements are shown in figures 23 and 24. These two measurements were taken with the sensor shown in figure 21, 2.54 cm away from the back plate of the outer tank. This position is favorable because the E vectors would be perpendicular

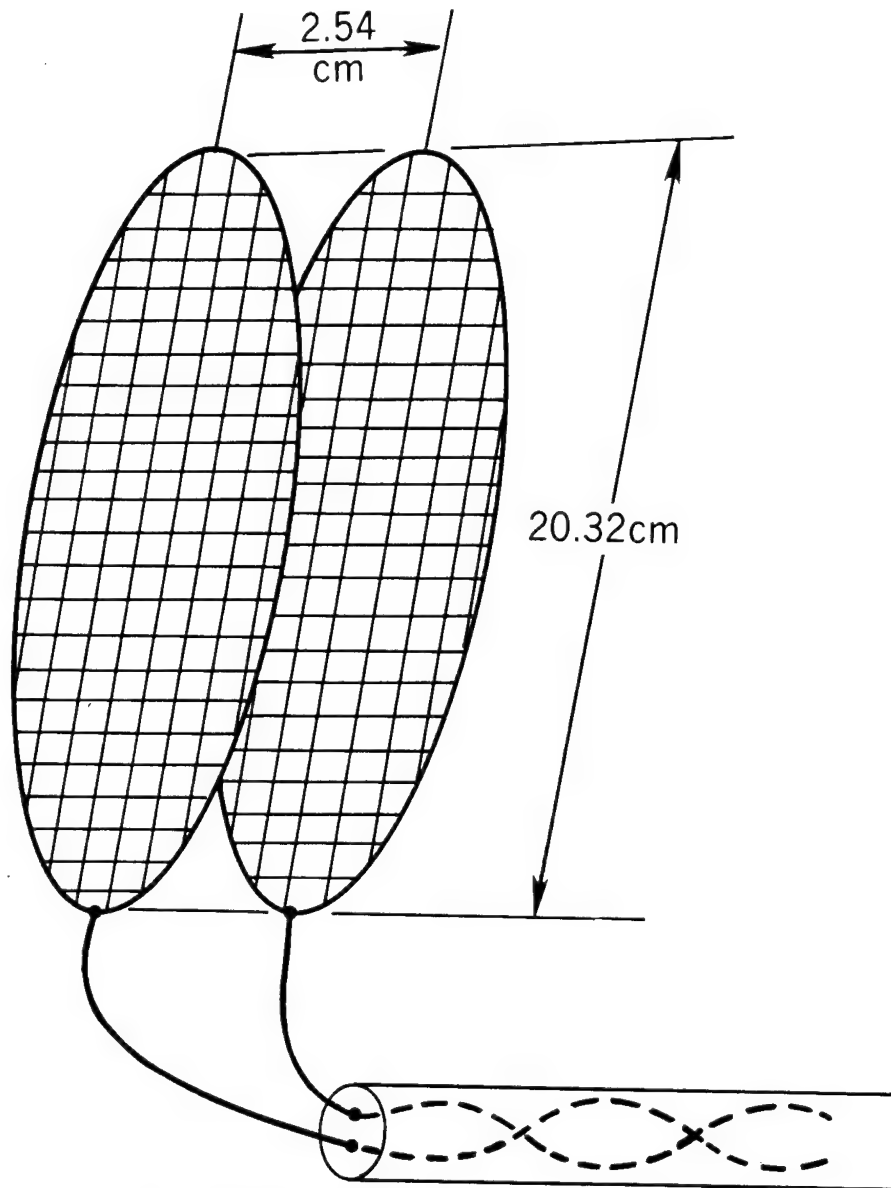


Figure 21. Whittaker  $\dot{E}$  sensor.

to the back plate and, therefore, perpendicular to the E-field sensor. The integration of the  $\dot{E}$  sensor measurements implies about 20,000 V between the pig and the outer cylinder.

In an effort to check our E-field measurements and also to investigate possible simulation techniques, the pig was subjected (fig. 25) to an AURORA gamma pulse while the pig was charged to (1) +2000 V and (2) -2000 V. The time constant of the power supply isolation was approximately 1 s. The results of these  $\dot{E}$  and integrated  $\dot{E}$  measurements are not consistent with an interpretation of the E-field

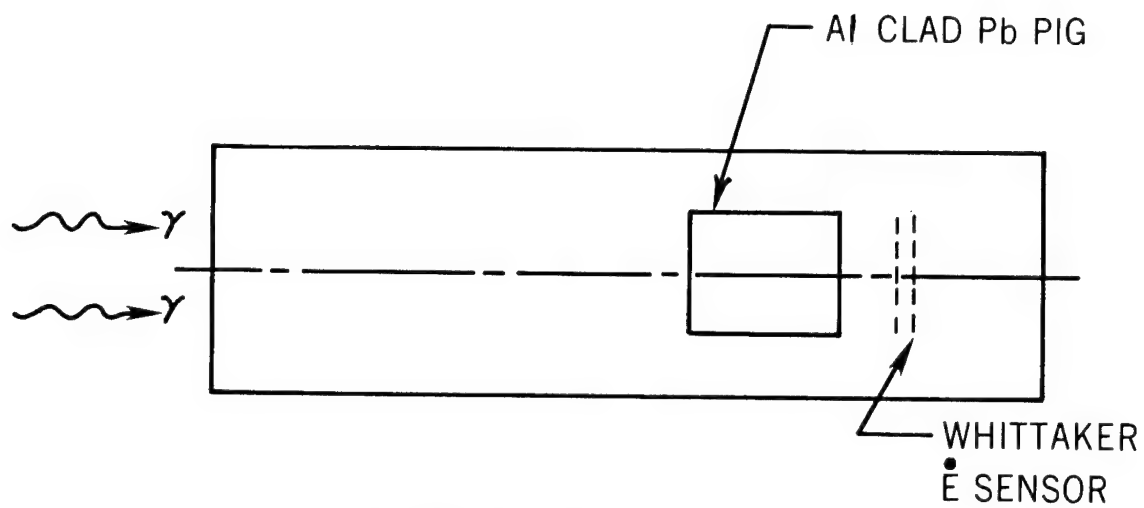


Figure 22. Floating pig.

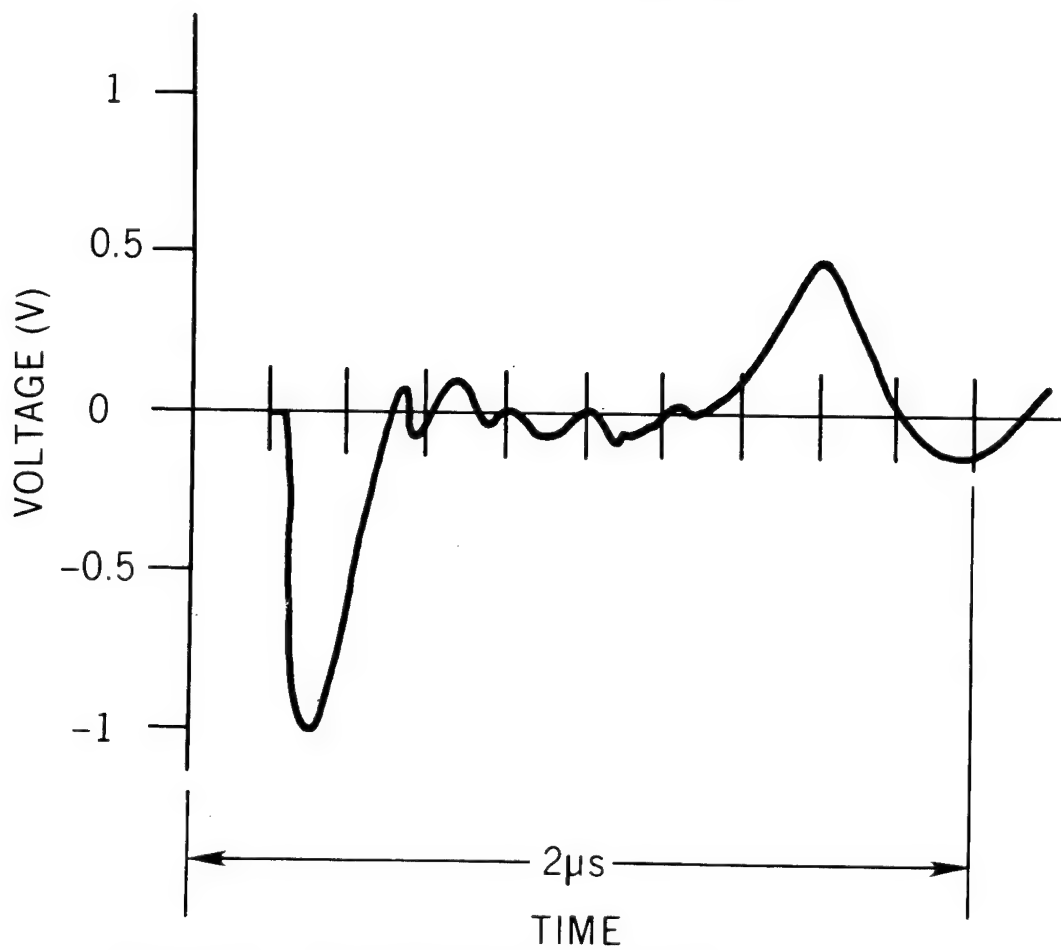


Figure 23. Output of  $\dot{E}$  sensor (oscilloscope trace).

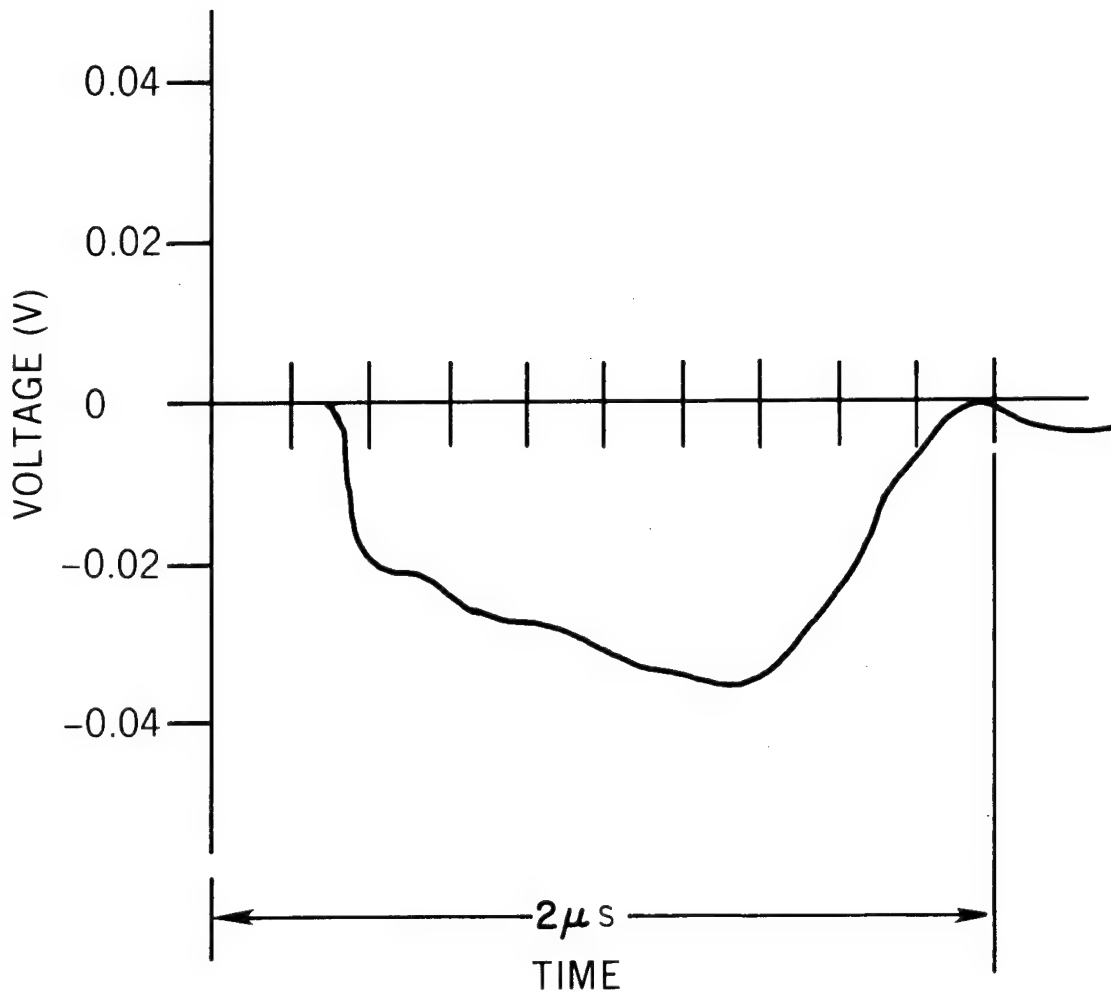


Figure 24. Integration of  $\dot{E}$  sensor response.

sensor that neglects the effects of a boundary-layer formation at the grids of the Whittaker  $\dot{E}$  sensor. The bias of  $\pm 2000$  V has a much more significant effect than one would expect if the Compton current produced by AURORA bremsstrahlung were really charging the pig to 20,000 V. Depending on the sign of the bias, the 2000-V bias either increases or decreases the E-field measurements by about 50 percent. If the pig were really charged to 20,000 V, the 2000 V bias should not have more than a 10-percent effect. A possible explanation of this disparity is the formation of a boundary layer on the sensor plate. The boundary-layer effects may have been increased by the grid structure of the  $\dot{E}$  sensor.

Although no definitive conclusions (based solely on any of these experiments) can be drawn concerning the feasibility of using a gamma-thick absorber as an E-field enhancer, the results lend insight

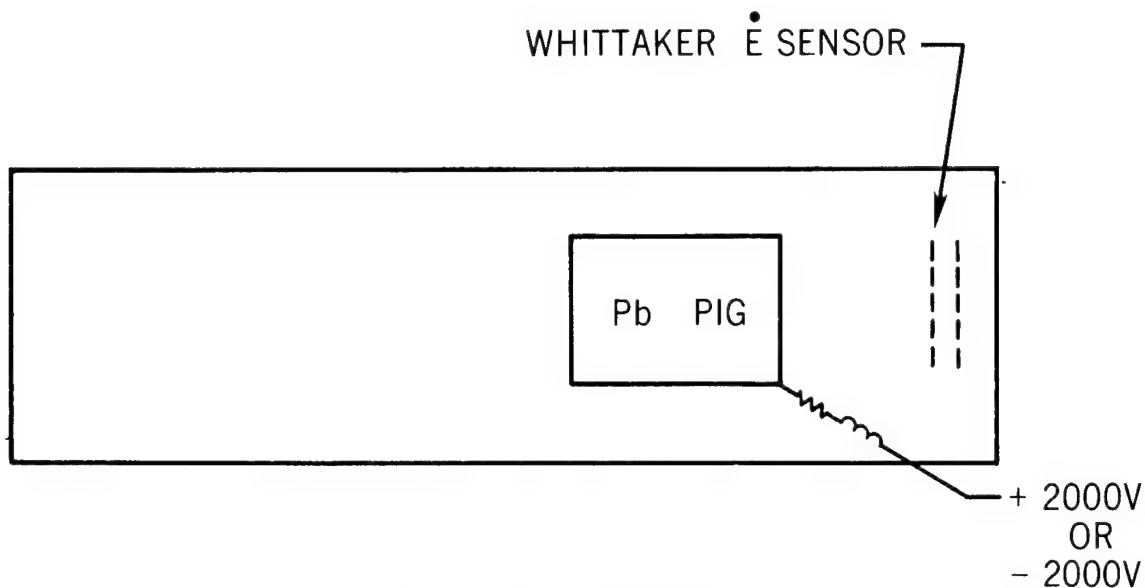


Figure 25. Charged pig.

into the phenomena of gamma-thick body charge collection and also indicate some of the potential engineering problems associated with using this as a method of simulation. These tentative indications are summarized below.

Because of the large conduction current term in equation (12), the significance of the  $\dot{E}$  sensor is hard to understand when it is surrounded by ionized air produced by gamma rays in the open AURORA test cell. The straightforward integration of the  $\dot{E}$  sensor yields rather large values of  $E$ . Boundary-layer effects also may be present.

To shield the  $\dot{E}$  sensor, it was placed behind a pig, and thus the significance of the conduction between the grids was reduced. The results of the integrated  $E$ -fields in air implied a very large pig voltage.

The gas conductivity was reduced further when the tank was filled with  $SF_6$ . The resulting  $\dot{E}$  measurements were large, as expected.

The pig was charged to 2000 V and subjected to the AURORA radiation. The results of the biasing appear to be inconsistent with the large  $E$ -fields implied by the measurements when the pig was not biased.

In light of the potential problems of boundary-layer interference in  $E$ -field measurements, a possible solution may be to use thin foils as the plates of the  $\dot{E}$  sensor.

#### 4. PLANS

In FY77, the major goals of TEMSEP to be fulfilled at HDL will continue the efforts of the study described in this report:

a. To develop adequate instrumentation to experimentally characterize the electromagnetic environment in the AURORA test cell.

b. To make the necessary measurements and perform theoretical calculations to fully and adequately characterize the electromagnetic environment in the AURORA test cell.

c. To develop an experimentally verified theoretical model for boundary-layer phenomena and determine the significance of such phenomena in tactical source-region situations of interest.

d. To theoretically determine the requirement for self-consistent interaction and coupling calculations for tactical source-region situations.

e. To develop an experimentally verified library of source-region coupling codes for tactical system applications.

f. To specify a technically feasible modification of the AURORA Facility for simulating worst-case source-region EMP environments of tactical interest. The simulation concept will be formulated in an attempt to accommodate both controlled diagonal experiments (oriented toward coupling code verification) and limited system or subsystem tests.

g. To perform state-of-the-art vulnerability estimates and, if necessary, make hardening recommendations for the AN/PRC-77 Radio Set and AN/TRC-145 Radio Terminal Set by using the existing EMP survivability criteria for tactical endoatmospheric threats.



#### LITERATURE CITED

- (1) J. F. W. Dietz, G. Merkel, and D. Spohn, Radiation Induced Coupling to a Truncated Cylinder within a Cylinder, IEEE Trans. Nucl. Sci., NS-23 (December 1976).
- (2) C. L. Longmire, Direct Interaction Effect in EMP, Air Force Weapons Laboratory, EMP Interaction Note 69 (November 1973).
- (3) R. A. Perala et al, Coupling Calculations for the LANCE Missile System in a Tactical Nuclear Environment (U), Mission Research Corp. Report No. AMRC-IR-76457 (March 1976). (SECRET RESTRICTED DATA).
- (4) R. A. Perala et al, Close-in Coupling Analysis of the AN/GRC-106 Radio System (U), Mission Research Corp. Report No. AMRC-IR-76458 (March 1976). (SECRET)
- (5) Daniel L. Goodwin, The LANCE Electromagnetic Pulse (EMP) Assessment--Endoatmospheric Threat (U), Harry Diamond Laboratories TM-77-14 (October 1977). (CONFIDENTIAL)
- (6) C. E. Baum, Radiation and Conductivity Constraints on the Design of a Dipole Electric Field Sensor, Air Force Weapons Laboratory EMP Sensor and Simulation Note 15 (June 1970).
- (7) P. A. Trimmer, Transient Radiation Effects on Basic Triode Amplifiers, Harry Diamond Laboratories TR-1197 (April 1964).

# DISTRIBUTION

DEFENSE DOCUMENTATION CENTER  
CAMERON STATION, BUILDING 5  
ALEXANDRIA, VA 22314  
ATTN DDC-TCA (12 COPIES)

COMMANDER  
USA RSCH & STD GP (EUR)  
BOX 65  
FPO NEW YORK 09510  
ATTN LTC JAMES M. KENNEDY, JR.  
CHIEF, PHYSICS & MATH BRANCH

COMMANDER  
US ARMY MATERIEL DEVELOPMENT  
& READINESS COMMAND  
5001 EISENHOWER AVENUE  
ALEXANDRIA, VA 22333  
ATTN DRXAM-TL, HQ TECH LIBRARY

COMMANDER  
US ARMY ARMAMENT MATERIEL  
READINESS COMMAND  
ROCK ISLAND ARSENAL  
ROCK ISLAND, IL 61201  
ATTN DRSAR-ASF, FUZE & MUNITIONS  
SPT DIV

COMMANDER  
USA MISSILE & MUNITIONS CENTER  
& SCHOOL  
REDSTONE ARSENAL, AL 35809  
ATTN ATSK-CTD-F

DIRECTOR  
ARMED FORCES RADIOBIOLOGY  
RESEARCH INSTITUTE  
DEFENSE NUCLEAR AGENCY  
NATIONAL NAVAL MEDICAL CENTER  
BETHESDA, MD 20014  
ATTN RPC  
ATTN TECHNICAL LIBRARY

ASSISTANT TO THE SECRETARY OF DEFENSE  
ATOMIC ENERGY  
DEPARTMENT OF DEFENSE  
WASHINGTON, DC 20301  
ATTN STAFF ASST (R&D)

DIRECTOR  
DEFENSE ADVANCED RSCH PROJ AGENCY  
ARCHITECT BUILDING  
1400 WILSON BLVD.  
ARLINGTON, VA 22209  
ATTN TECHNICAL LIBRARY  
ATTN AD/E&PS

DIRECTOR  
DEFENSE CIVIL PREPAREDNESS AGENCY  
ASSISTANT DIRECTOR FOR RESEARCH  
WASHINGTON, DC 20301  
ATTN TS(AED)  
ATTN RE(EO)  
ATTN ADMIN OFFICER  
ATTN PO(SE)

DEFENSE COMMUNICATION ENGINEER CENTER  
1860 WIEHLE AVENUE  
RESTON, VA 22090  
ATTN CODE R720, C. STANSBERRY  
ATTN CODE R400  
ATTN CODE R123, TECH LIB

DIRECTOR  
DEFENSE COMMUNICATIONS AGENCY  
WASHINGTON, DC 20305  
ATTN CODE 930, MONTE I. BURGETT, FR  
ATTN CCTC C312  
ATTN CCTC/C672  
ATTN CCTC C313  
ATTN CODE 545

COMMANDER  
DEFENSE ELECTRONIC SUPPLY CENTER  
1507 WILMINGTON PIKE  
DAYTON, OH 45401  
ATTN ECS  
ATTN ROSS V. DOUGHTY  
ATTN EQ

DIRECTOR  
DEFENSE INTELLIGENCE AGENCY  
WASHINGTON, DC 20301  
ATTN RDS-3A  
ATTN DB-4C, EDWARD OFARRELL  
ATTN RDS-3A4, POMPONIO PLAZA

DIRECTOR  
DEFENSE NUCLEAR AGENCY  
WASHINGTON, DC 20305  
ATTN RATN  
ATTN DDST  
ATTN RAEV  
ATTN TITL TECH LIBRARY  
ATTN TISI ARCHIVES  
ATTN STVL  
ATTN RAAE

DIRECTOR OF DEFENSE RESEARCH  
& ENGINEERING  
DEPARTMENT OF DEFENSE  
WASHINGTON, DC 20301  
ATTN S&SS(OS)  
ATTN G. BARSE

COMMANDER  
FIELD COMMAND  
DEFENSE NUCLEAR AGENCY  
KIRTLAND AFB, NM 87115  
ATTN FCPR  
ATTN FCSM-F3/CDR SMITH  
ATTN FCLMC

DIRECTOR  
INTERSERVICE NUCLEAR WEAPONS SCHOOL  
KIRTLAND AFB, NM 87115  
ATTN DOCUMENT CONTROL

DIRECTOR  
JOINT STRATEGIC TARGET  
PLANNING STAFF, JCS  
OFFUTT AFB  
OMAHA, NB 68113  
ATTN STINFO LIBRARY  
ATTN JSAS  
ATTN JLTW-2

CHIEF  
LIVERMORE DIVISION, FIELD COMMAND DNA  
LAWRENCE LIVERMORE LABORATORY  
P.O. BOX 808  
LIVERMORE, CA 94550  
ATTN FCPR

NATIONAL COMMUNICATIONS SYSTEM  
OFFICE OF THE MANAGER  
WASHINGTON, DC 20305  
ATTN NCS-TS, CHARLES D. BODSON

DIRECTOR  
NATIONAL SECURITY AGENCY  
FT. GEORGE G. MEADE, MD 20755  
ATTN O. O. VAN GUNTEN, R-425  
ATTN TECHNICAL LIBRARY  
ATTN R522  
ATTN T1213  
ATTN TDL  
ATTN T412

OJCS/J-3  
THE PENTAGON  
WASHINGTON, DC 20301  
ATTN J-3

PROJECT MANAGER  
ARMY TACTICAL DATA SYSTEMS  
US ARMY ELECTRONICS COMMAND  
FORT MONMOUTH, NJ 07703  
ATTN DRCPM-TDS-BSI

DIRECTOR  
BMD ADVANCED TECH CTR  
HUNTSVILLE OFFICE  
PO BOX 1500  
HUNTSVILLE, AL 35807  
ATTN ATC-T

COMMANDER  
BMD SYSTEM COMMAND  
P.O. BOX 1500  
HUNTSVILLE, AL 35807  
ATTN BMDSC-AOLIB

COMMANDER  
US ARMY ARMOR CENTER  
FORT KNOX, KY 40121  
ATTN TECHNICAL LIBRARY

DIRECTOR  
US ARMY BALLISTIC RESEARCH LABS  
ABERDEEN PROVING GROUND, MD 21005  
ATTN DRSTE-EL  
ATTN DRXBR-AM, W. R. VANANTWERP  
ATTN DRDAR-BLE

COMMANDER  
US ARMY COMM-ELEC ENGRG INSTAL AGY  
FT HUACHUCA, AZ 85613  
ATTN CCC-PRSO-S  
ATTN CCC-CED-SES

COMMANDER  
US ARMY COMMUNICATIONS COMMAND  
FORT HUACHUCA, AZ 85613  
ATTN CC-OPS-OS  
ATTN CC-ENGR  
ATTN CC-OPS-PD

COMMANDER  
US ARMY COMMUNICATIONS COMMAND  
COMBAT DEVELOPMENT DIVISION  
FT. HUACHUCA, AZ 85613  
ATTN ATSI-CD-MD

# DISTRIBUTION (Cont'd)

CHIEF  
US ARMY COMMUNICATIONS SYSTEMS AGENCY  
FORT MONMOUTH, NJ 07703  
ATTN CCM-RD-T, CCM-AD-SV

COMMANDER  
US ARMY ELECTRONICS COMMAND  
FORT MONMOUTH, NJ 07703  
ATTN DRSEL-CT-HDK, ABRAHAM E. COHEN  
ATTN DRSEL-TL-MD, GERHART K. GAULE  
ATTN DRSEL-GG-TD, W. R. WERK  
ATTN DRSEL-TL-ME  
ATTN DRSEL-NL-RO, R. BROWN

COMMANDER  
US ARMY ELECTRONICS PROVING GROUND  
FORT HUACHUCA, AZ 85613  
ATTN STEEP-MT-M, GERALD W. DURBIN

DIVISION ENGINEER  
US ARMY ENGINEER DIV HUNTSVILLE  
P.O. BOX 1600, WEST STATION  
HUNTSVILLE, AL 35807  
ATTN HNDED-SR

US ARMY INTEL THREAT  
ANALYSIS DETACHMENT  
ROOM 2201, BLDG A  
ARLINGTON HALL STATION  
ARLINGTON, VA 22212  
ATTN RM 2200, BLDG A

COMMANDER  
US ARMY INTELLIGENCE & SEC COMMAND  
ARLINGTON HALL STATION  
4000 ARLINGTON BLVD  
ARLINGTON, VA 22212  
ATTN TECHNICAL LIBRARY  
ATTN TECH INFO FAC

DIRECTOR  
US ARMY MATERIEL SYS  
ANALYSIS ACTIVITY  
ABERDEEN PROVING GROUND, MD 21005  
ATTN DRXS-CC  
ATTN DRXS-PO

COMMANDER  
US ARMY MISSILE RES & DEV COMMAND  
REDSTONE ARSENAL, AL 35809  
ATTN DRDMI-EAA  
ATTN DRDMI-TBD  
ATTN DRCPM-PE-EA, WALLACE O. WAGNER  
ATTN DRCPM-PE-EG, WILLIAM B. JOHNSON

COMMANDER  
US ARMY MISSILE MATERIEL  
READINESS COMMAND  
REDSTONE ARSENAL, AL 35809  
ATTN DRCPM-LCEX, HOWARD H. HENRIKSEN  
ATTN DRSMI-TRA, FAISON P. GIBSON

COMMANDER  
US ARMY TANK AUTOMOTIVE COMMAND  
WARREN, MI 48090  
ATTN DRCPM-GCM-SW, LYLE A. WOLCOTT

COMMANDER  
US ARMY TEST AND EVALUATION COMMAND  
ABERDEEN PROVING GROUND, MD 21005  
ATTN DRSTE-FA

COMMANDER  
US ARMY TRAINING AND DOCTRINE COMMAND  
FORT MONROE, VA 23651  
ATTN ATORI-OP-SW

PROJECT OFFICER  
US ARMY TAC COMM SYSTEMS  
US ARMY ELECTRONICS COMMAND  
FT MONMOUTH, NJ 07703  
ATTN DRCPM-ATC

COMMANDER  
WHITE SANDS MISSILE RANGE  
WHITE SANDS MISSILE RANGE, NM 88002  
ATTN D. E. MILLER  
ATTN TE-AN, MR. OKUMA

CHIEF OF NAVAL RESEARCH  
DEPARTMENT OF THE NAVY  
ARLINGTON, VA 22217  
ATTN CODE 464, R. GRACEN JOINER  
ATTN CODE 427

OFFICER-IN-CHARGE  
CIVIL ENGINEERING LABORATORY  
NAVAL CONSTRUCTION BATTALION CENTER  
PORT HUENEME, CA 93041  
ATTN TECHNICAL LIBRARY

COMMANDER  
NAVAL AIR SYSTEMS COMMAND  
HEADQUARTERS  
WASHINGTON, DC 21360  
ATTN AIR-350F

COMMANDER  
NAVAL ELECTRONIC SYSTEMS COMMAND  
HEADQUARTERS  
WASHINGTON, DC 20360  
ATTN PME-117-215

COMMANDER  
NAVAL OCEAN SYSTEMS CENTER  
SAN DIEGO, CA 92152  
ATTN CODE 812, S. W. LICHTMAN  
ATTN CODE 015, C. FLETCHER  
ATTN RESEARCH LIBRARY

SUPERINTENDENT (CODE 1424)  
NAVAL POSTGRADUATE SCHOOL  
MONTEREY, CA 93940  
ATTN CODE 1424

COMMANDING OFFICER  
NAVAL ORDNANCE STATION  
INDIAN HEAD, MD 20640  
ATTN STANDARDIZATION DEPT

DIRECTOR  
NAVAL RESEARCH LABORATORY  
WASHINGTON, DC 20375  
ATTN CODE 4104, EMANUAL L. BRANCATO  
ATTN CODE 2627, DORIS R. FOLEN  
ATTN CODE 7701, JACK D. BROWN  
ATTN CODE 7750  
ATTN CODE 6624  
ATTN CODE 6623, RICHARD L. STATLER

COMMANDER  
NAVAL SHIP ENGINEERING CENTER  
DEPARTMENT OF THE NAVY  
WASHINGTON, DC 20362  
(HYATTSVILLE)  
ATTN CODE 6174D2, EDWARD F. DUFFY

COMMANDER  
NAVAL SURFACE WEAPONS CENTER  
WHITE OAK, SILVER SPRING, MD 20910  
ATTN CODE 431, EDWIN R. RATHBURN  
ATTN L. LIBELLO, CODE WR43  
ATTN CODE WA51RH, RM 130-108

COMMANDER  
NAVAL WEAPONS CENTER  
CHINA LAKE, CA 93555  
ATTN CODE 533, TECH LIB

DIRECTOR  
STRATEGIC SYSTEMS PROJECT OFFICE  
NAVY DEPARTMENT  
WASHINGTON, DC 20376  
ATTN NSP-2431, GERALD W. HOSKINS  
ATTN NSP-230, DAVID GOLD  
ATTN NSP-43, TECH LIB  
ATTN NSP-27334  
ATTN SP 2701, JOHN W. PITSENBERGER  
ATTN NSP-2342, RICHARD L. COLEMAN

COMMANDER  
US NAVAL COASTAL SYSTEMS LABORATORY  
PANAMA CITY, FL 32401  
ATTN TECH LIB

COMMANDER  
ADC/DE  
ENT AFB, CO 80912  
ATTN DEEDS, JOSEPH C. BRANNAN

AF WEAPONS LABORATORY, AFSC  
KIRTLAND AFB, NM 87117  
ATTN NT, CARL E. BAUM  
ATTN SUL  
ATTN ELA, J. P. CASTILLO  
ATTN NTS  
ATTN SAB  
ATTN ELXT  
ATTN NT  
ATTN CA  
ATTN NTN  
ATTN ELP

AFTAC  
PATRICK AFB, FL 32925  
ATTN TFS, MAJ MARION F. SCHNEIDER  
ATTN TFE

COMMANDER  
AIR UNIVERSITY  
MAXWELL AFB, AL 36112  
ATTN AUL/LSE-70-250

COMMANDER  
ASD  
WPAFB, OH 45433  
ATTN ENFTV

HEADQUARTERS  
ELECTRONIC SYSTEMS DIVISION/YS  
HANSCOM AFB, MA 01731  
ATTN YSEV

COMMANDER  
FOREIGN TECHNOLOGY DIVISION, AFSC  
WRIGHT-PATTERSON AFB, OH 45433  
ATTN NICD LIBRARY  
ATTN ETD, B. L. BALLARD

DISTRIBUTION (Cont'd)

COMMANDER  
OGDEN AIR LOGISTICS CENTER  
HILL AFB, UT 84401  
ATTN OO-ALC/MMETH, P. W. BERTHEL  
ATTN MAJ RONALD BLACKBURN  
ATTN MMEDO, LEO KIDMAN

COMMANDER  
ROME AIR DEVELOPMENT CENTER, AFSC  
GRIFFISS AFB, NY 13440  
ATTN TSLD

COMMANDER  
SACRAMENTO AIR LOGISTICS CENTER  
MCLELLAN AFB, CA 95652  
ATTN MMSREM, F. R. SPEAR  
ATTN MMARA, J. D. DUGAN  
ATTN MMEAE, C. E. HOWARD  
ATTN MMCRS, H. A. PELMASTRO  
ATTN MMIRA, J. W. DEMES

SAMSO/IN  
POST OFFICE BOX 92960  
WORLDWAY POSTAL CENTER  
LOS ANGELES, CA 90009  
(INTELLIGENCE)  
ATTN IND, I. J. JUDY

SAMSO/MN  
NORTON AFB, CA 92409  
(MINUTEMAN)  
ATTN MNMH, MAJ M. BARAN  
ATTN MNMH, CAPT R. I. LAWRENCE

SAMSO/SK  
POST OFFICE BOX 92960  
WORLDWAY POSTAL CENTER  
LOS ANGELES, CA 90009  
(SPACE COMM SYSTEMS)  
ATTN SKF

SAMSO/YA  
POST OFFICE BOX 92960  
WORLDWAY POSTAL CENTER  
LOS ANGELES, CA 90009  
ATTN YAPC

COMMANDER IN CHIEF  
STRATEGIC AIR COMMAND  
OFFUTT AFB, NB 68113  
ATTN NRI-STINFO LIBRARY  
ATTN XPFS, MAJ BRIAN STEPHAN  
ATTN DEL  
ATTN JPST  
ATTN JLTW  
ATTN GARNET E. MATZKE

UNIVERSITY OF CALIFORNIA  
LAWRENCE LIVERMORE LABORATORY  
P.O. BOX 808  
LIVERMORE, CA 94550  
ATTN TERRY R. DONICH, L-96  
ATTN HANS KRUGER, L-96  
ATTN LIBRARIAN  
ATTN WILLIAM J. HOGAN, L-389  
ATTN DONALD J. MEEKER, L-545

LOS ALAMOS SCIENTIFIC LABORATORY  
P.O. BOX 1663  
LOS ALAMOS, NM 87545  
ATTN DOC CON FOR CLARENCE BENTON  
ATTN DOC CON FOR JOHN S. MALIK

SANDIA LABORATORIES  
PO BOX 5800  
ALBUQUERQUE, NM 87115  
ATTN DOC CON FOR ORD 9353,  
R. L. PARKER  
ATTN DOC CON FOR ELMER F. HARTMAN  
ATTN C. N. VITTITOE, 5231

US ENERGY RSCH & DEV ADMIN  
ALBUQUERQUE OPERATIONS OFFICE  
P.O. BOX 5400  
ALBUQUERQUE, NM 87115  
ATTN OPERATIONAL SAFETY DIV  
ATTN DOC CON FOR TECH LIBRARY

CENTRAL INTELLIGENCE AGENCY  
ATTN: RD/SI, RM 5G48 HQ BLDG  
WASHINGTON, DC 20505  
ATTN OSI/NED/NWB

ADMINISTRATOR  
DEFENSE ELECTRIC POWER ADMIN  
DEPARTMENT OF THE INTERIOR  
INTERIOR SOUTH BLDG, 312  
WASHINGTON, DC 20240  
ATTN L. O'NEILL

DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION  
HEADQUARTERS SEC DIV, ASE-300  
800 INDEPENDENCE AVENUE, SW  
WASHINGTON, DC 20591  
ATTN SEC DIV ASE-300

NATIONAL OCEANIC & ATMOSPHERIC ADMIN  
ENVIRONMENTAL RESEARCH LABORATORIES  
DEPARTMENT OF COMMERCE  
BOULDER, CO 80302  
ATTN GLENN JEAN

AEROSPACE CORPORATION  
PO BOX 92957  
LOS ANGELES, CA 90009  
ATTN C. B. PEARLSTON  
ATTN IRVING M. GARFUNKEL  
ATTN JULIAN REINHEIMER  
ATTN LIBRARY  
ATTN CHARLES GREENHOW

AGBABIAN ASSOCIATES  
250 NORTH NASH STREET  
EL SEGUNDO, CA 90245  
ATTN LIBRARY

AVCO RESEARCH & SYSTEMS GROUP  
201 LOWELL STREET  
WILMINGTON, MA 01887  
ATTN W. LEPSEVICH

BATTELLE MEMORIAL INSTITUTE  
505 KING AVENUE  
COLUMBUS, OH 43201  
ATTN ROBERT M. BLAZEK  
ATTN EUGENE R. LEACH

BDM CORPORATION, THE  
7915 JONES BRANCH DRIVE  
MCLEAN, VA 22101  
ATTN TECHNICAL LIBRARY

BDM CORPORATION, THE  
P.O. BOX 9274  
ALBUQUERQUE INTERNATIONAL  
ALBUQUERQUE, NM 87119  
ATTN TECH LIB

BENDIX CORPORATION, THE  
NAVIGATION AND CONTROL GROUP  
TETERBORO, NJ 07608  
ATTN DEPT 6401

BOEING COMPANY, THE  
P.O. BOX 3707  
SEATTLE, WA 98124  
ATTN D. E. ISBELL  
ATTN HOWARD W. WICKLEIN, MS 17-11  
ATTN DAVID KEMLE  
ATTN KENT TECH LIB  
ATTN B. C. HANRAHAN

BOOZ-ALLEN AND HAMILTON, INC.  
106 APPLE STREET  
TINTON FALLS, NJ 07724  
ATTN RAYMOND J. CHRISNER  
ATTN TECH LIB

BROWN ENGINEERING COMPANY, INC.  
CUMMINGS RESEARCH PARK  
HUNTSVILLE, AL 35807  
ATTN FRED LEONARD

BURROUGHS CORPORATION  
FEDERAL AND SPECIAL SYSTEMS GROUP  
CENTRAL AVE AND ROUTE 252  
P.O. BOX 517  
PAOLI, PA 19301  
ATTN ANGELO J. MAURIELLO

CALSPAN CORPORATION  
P.O. BOX 235  
BUFFALO, NY 14221  
ATTN TECHNICAL LIBRARY

CHARLES STARK DRAPER LABORATORY INC  
555 TECHNOLOGY SQUARE  
CAMBRIDGE, MA 02139  
ATTN TIC, MS 74  
ATTN KENNETH FERTIG

CINCINNATI ELECTRONICS CORPORATION  
2630 GLENDALE - MILFORD ROAD  
CINCINNATI, OH 45241  
ATTN LOIS HAMMOND

COMPUTER SCIENCES CORPORATION  
P.O. BOX 530  
6565 ARLINGTON BLVD  
FALLS CHURCH, VA 22046  
ATTN RAMONA BRIGGS

COMPUTER SCIENCES CORPORATION  
201 LA VETA DRIVE, NE  
ALBUQUERQUE, NM 87108  
ATTN ALVIN SCHIFF

CONTROL DATA CORPORATION  
P.O. BOX 0  
MINNEAPOLIS, MN 55440  
ATTN JACK MEEHAN

CUTLER-HAMMER, INC.  
AII DIVISION  
COMAC ROAD  
DEER PARK, NY 11729  
ATTN EDWARD KARPEN

DIKEWOOD INDUSTRIES, THE  
1009 BRADBURY DRIVE, SE  
ALBUQUERQUE, NM 87106  
ATTN TECH LIB  
ATTN L. WAYNE DAVIS

DISTRIBUTION (Cont'd)

|  |  |  |
|--|--|--|
| E-SYSTEMS INCORPORATED<br>ECI DIVISION<br>1501 DIVISION<br>1501 72ND STREET NORTH<br>ST PETERSBURG, FL 33733<br>ATTN RAYMOND D. FRANK  | GENERAL ELECTRIC COMPANY<br>AEROSPACE ELECTRONICS SYSTEMS<br>FRENCH ROAD<br>UTICA, NY 13503<br>ATTN CHARLES M. HEWISON, DROP 624   | HUGHES AIRCRAFT COMPANY<br>CENTINELLA AND TEALE<br>CULVER CITY, CA 90230<br>ATTN CTCOC 6/E110<br>ATTN JOHN B. SINGLETARY, MS 6-D133  |
| E-SYSTEMS, INC.<br>GREENVILLE DIVISION<br>P.O. BOX 1056<br>GREENVILLE, TX 75401<br>ATTN JOLETA MOORE   | GENERAL ELECTRIC COMPANY-TEMPO<br>ATTN: DASIAC<br>C/O DEFENSE NUCLEAR AGENCY<br>WASHINGTON, DC 20305<br>ATTN WILLIAM ALFONTE<br>ATTN ED ARNOLD   | IIT RESEARCH INSTITUTE<br>ELECTROMAG COMPATABILITY ANAL CTR<br>NORTH SEVERN<br>ANNAPOLIS, MD 21402<br>ATTN ACOAT   |
| EFFECTS TECHNOLOGY, INC.<br>5383 HOLLISTER AVENUE<br>SANTA BARBARA, CA 93111<br>ATTN S. CLOW   | GENERAL RESEARCH CORPORATION<br>P.O. BOX 3587<br>SANTA BARBARA, CA 93105<br>ATTN TECH INFO OFFICE  | IIT RESEARCH INSTITUTE<br>10 WEST 35TH STREET<br>CHICAGO, IL 60616<br>ATTN IRVING N. MINDEL<br>ATTN JACK E. BRIDGES  |
| EG&G, INC.<br>ALBUQUERQUE DIVISION<br>PO BOX 10218<br>ALBUQUERQUE, NM 87114<br>ATTN C. GILES   | GEORGIA INSTITUTE OF TECHNOLOGY<br>GEORGIA TECH RESEARCH INSTITUTE<br>ATLANTA, GA 30332<br>ATTN R. CURRY   | INSTITUTE FOR DEFENSE ANALYSES<br>400 ARMY-NAVY DRIVE<br>ARLINGTON, VA 22202<br>ATTN TECH INFO OFC   |
| FAIRCHILD CAMERA AND INSTRUMENT CORP<br>464 ELLIS STREET<br>MOUNTAIN VIEW, CA 94040<br>ATTN SEC DEPT FOR 2-233,<br>DAVID K. MYERS  | GEORGIA INSTITUTE OF TECHNOLOGY<br>OFFICE OF CONTRACT ADMINISTRATION<br>ATTN: RSCH SECURITY COORDINATOR<br>ATLANTA, GA 30332<br>ATTN RES & SEC COORD FOR HUGH DENNY  | INTL TEL & TELEGRAPH CORPORATION<br>500 WASHINGTON AVENUE<br>NUTLEY, NJ 07110<br>ATTN TECHNICAL LIBRARY  |
| FORD AEROSPACE & COMMUNICATIONS CORP<br>3939 FABIAN WAY<br>PALO ALTO, CA 94303<br>ATTN LIBRARY<br>ATTN J. T. MATTINGLEY, MS X22<br>ATTN DONALD R. MCMORROW MS G30                                | GRUMMAN AEROSPACE CORPORATION<br>SOUTH OYSTER BAY ROAD<br>BETHPAGE, NY 11714<br>ATTN L-01 35   | ION PHYSICS CORPORATION<br>SOUTH BEDFORD STREET<br>BURLINGTON, MA 01803<br>ATTN ROBERT D. EVANS  |
| FORD AEROSPACE & COMMUNICATIONS<br>OPERATIONS<br>FORD & JAMBOREE ROADS<br>NEWPORT BEACH, CA 92663<br>ATTN KEN C. ATTINGER<br>ATTN E. R. PONCELET, JR.  | GTE SYLVANIA, INC.<br>ELECTRONICS SYSTEMS GRP-EASTERN DIV<br>77 A STREET<br>NEEDHAM, MA 02194<br>ATTN CHARLES A. THORNHILL, LIBRARIAN<br>ATTN LEONARD L. BLAISDELL   | IRT CORPORATION<br>P.O. BOX 81087<br>SAN DIEGO, CA 92138<br>ATTN DENNIS SWIFT<br>ATTN C. B. WILLIAMS   |
| FRANKLIN INSTITUTE, THE<br>20TH STREET AND PARKWAY<br>PHILADELPHIA, PA 19103<br>ATTN RAMIE H. THOMPSON   | GTE SYLVANIA, INC.<br>189 B STREET<br>NEEDHAM HEIGHTS, MA 02194<br>ATTN CHARLES H. RAMSBOTTOM<br>ATTN DAVID P. FLOOD<br>ATTN COMM SYST DIV, EMIL P. MOTCHOK<br>ATTN H & V GROUP, MARIO A. NUREFORA<br>ATTN J. A. WALDRON | JAYCOR<br>1401 CAMINO DEL MAR<br>DEL MAR, CA 92014<br>ATTN ERIC P. WENNAAS<br>ATTN RALPH H. STAHL  |
| GENERAL DYNAMICS CORP<br>CONVAIR DIVISION<br>P.O. BOX 80847<br>SAN DIEGO, CA 92138<br>ATTN RSCH LIB  | HARRIS CORPORATION<br>HARRIS SEMICONDUCTOR DIVISION<br>P.O. BOX 883<br>MELBOURNE, FL 32901<br>ATTN V. PRES & MGR PRGMS DIV   | JAYCOR<br>205 S WHITTING STREET, SUITE 500<br>ALEXANDRIA, VA 22304<br>ATTN TECH LIB  |
| GENERAL DYNAMICS CORP<br>ELECTRONICS DIVISION<br>P.O. BOX 81127<br>SAN DIEGO, CA 92138<br>ATTN RSCH LIB  | HONEYWELL INCORPORATED<br>AVIONICS DIVISION<br>2600 TIDGWAY PARKWAY<br>MINNEAPOLIS, MN 55413<br>ATTN RONALD R. JOHNSON, A1622<br>ATTN S&RC LIB   | KAMAN SCIENCES CORPORATION<br>P.O. BOX 7463<br>COLORADO SPRINGS, CO 80933<br>ATTN ALBERT P. BRIDGES<br>ATTN W. FOSTER RICH<br>ATTN WALTER E. WARE<br>ATTN JERRY I. LUBELL<br>ATTN JOHN R. HOFFMAN<br>ATTN FRANK H. SHELTON |
| GENERAL ELECTRIC COMPANY<br>ORDNANCE SYSTEMS<br>100 PLASTICS AVENUE<br>PITTSFIELD, MA 01201<br>ATTN JOSEPH J. REIDL  | HONEYWELL INCORPORATED<br>AVIONICS DIVISION<br>13350 US HIGHWAY 19 NORTH<br>ST. PETERSBURG, FL 33733<br>ATTN W. E. STEWART<br>ATTN M.S. 725-5, STACEY H. GRAFF   | LITTON SYSTEMS, INC.<br>DATA SYSTEMS DIVISION<br>8000 WOODLEY AVENUE<br>VAN NUYS, CA 91409<br>ATTN MB48-61<br>ATTN EMC GP  |
| GENERAL ELECTRIC COMPANY<br>TEMPO-CENTER FOR ADVANCED STUDIES<br>816 STATE STREET (PO DRAWER QQ)<br>SANTA BARBARA, CA 93102<br>ATTN DASIAC<br>ATTN ROYDEN R. RUTHERFORD<br>ATTN WILLIAM MCNAMERA |  | LITTON SYSTEMS, INC.<br>GUIDANCE & CONTROL SYSTEMS DIVISION<br>5500 CANOGA AVENUE<br>WOODLAND HILLS, CA 91364<br>ATTN JOE MOYER  |

DISTRIBUTION (Cont'd)

LITTON SYSTEMS, INC.  
AMECOM DIVISION  
5115 CALVERT ROAD  
COLLEGE PARK, MD 20740  
ATTN J. SKAGGS

LOCKHEED MISSILES AND SPACE  
COMPANY, INC.  
P.O. BOX 504  
SUNNYVALE, CA 94088  
ATTN DEPT 85-85, SAMUEL I. TAIMUTY  
ATTN G. F. HEATH, D/81-14  
ATTN EDWIN A. SMITH, DEPT 85-85  
ATTN H. E. THAYN  
ATTN L. ROSSI, DEPT 81-64  
ATTN BENJAMIN T. KIMURA, DEPT 81-14  
ATTN M. J. BERNSTEIN

LOCKHEED MISSILES AND SPACE CO INC  
3251 HANOVER STREET  
PALO ALTO, CA 94304  
ATTN TECH INFO CTR, D/COLL

M.I.T. LINCOLN LABORATORY  
P.O. BOX 73  
LEXINGTON, MA 02173  
ATTN LEONA LOUGHLIN, LIBRARIAN A-082

MARTIN MARIETTA AEROSPACE  
ORLANDO DIVISION  
P.O. BOX 5837  
ORLANDO, FL 32805  
ATTN MONA C. GRIFFITH, LIB MP-30

MAXWELL LABORATORIES, INC.  
9244 BALBOA AVENUE  
SAN DIEGO, CA 92123  
ATTN A. W. TRAVELPIECE

MCDONNELL DOUGLAS CORPORATION  
POST OFFICE BOX 516  
ST. LOUIS, MO 63166  
ATTN TOM ENDER

MCDONNELL DOUGLAS CORPORATION  
5301 BOLSA AVENUE  
HUNTINGTON BEACH, CA 92647  
ATTN STANLEY SCHNEIDER  
ATTN TECH LIBRARY SERVICES

MISSION RESEARCH CORPORATION  
735 STATE STREET  
SANTA BARBARA, CA 93101  
ATTN WILLIAM C. HART  
ATTN EMP GROUP

MISSION RESEARCH CORPORATION  
P.O. BOX 8693, STATION C  
ALBUQUERQUE, NM 87108  
ATTN DAVID E. MEREWETHER  
ATTN L. N. MCCORMICK

MISSION RESEARCH CORPORATION-SAN  
DIEGO  
P.O. BOX 1209  
LA JOLLA, CA 92038  
ATTN V. A. J. VAN LINT

MITRE CORPORATION, THE  
P.O. BOX 208  
BEDFORD, MA 01730  
ATTN THEODORE JARVIS  
ATTN M. E. FITZGERALD

NORTHROP CORPORATION  
NORTHROP RESEARCH AND  
TECHNOLOGY CENTER  
3401 WEST BROADWAY  
HAWTHORNE, CA 90250  
ATTN LIBRARY

NORTHROP CORPORATION  
ELECTRONIC DIVISION  
2301 WEST 120TH STREET  
HAWTHORNE, CA 90250  
ATTN VINCENT R. DEMARTINO  
ATTN TECH LIB  
ATTN LEW SMITH  
ATTN RAD EFFECTS GRP, B. AHLPORT

PHYSICS INTERNATIONAL COMPANY  
2700 MERCED STREET  
SAN LEANDRO, CA 94577  
ATTN DOC CON

PULSAR ASSOCIATES, INC.  
7911 HERSCHEL AVENUE  
LA JOLLA, CA 92037  
ATTN V. FARGO  
ATTN SECURITY

R & D ASSOCIATES  
PO BOX 9695  
MARINA DEL REY, CA 90291  
ATTN S. CLAY ROGERS  
ATTN LEONARD SCHLESSINGER  
ATTN CHARLES MO  
ATTN RICHARD R. SCHAEFER  
ATTN DOC CON

RAND CORPORATION, THE  
1700 MAIN STREET  
SANTA MONICA, CA 90406  
ATTN LIB-D  
ATTN CULLEN CRAIN

RAY PROOF CORPORATION  
P.O. BOX 60  
NORWICK, CT 06856  
ATTN E. S. KESNER

RAYTHEON COMPANY  
HARTWELL ROAD  
BEDFORD, MA 01730  
ATTN GAJANAN H. JOSHI,  
RADAR SYS LAB

RAYTHEON COMPANY  
528 BOSTON POST ROAD  
SUDBURY, MA 01776  
ATTN HAROLD L. FLESCHER

RCA CORPORATION  
GOVERNMENT SYSTEMS DIVISION  
ASTRO ELECTRONICS  
PO BOX 800, LOCUST CORNER  
EAST WINDSOR TOWNSHIP  
PRINCETON, NJ 08540  
ATTN GEORGE J. BRUCKER

RCA CORPORATION  
CAMDEN COMPLEX  
FRONT & COOPER STREETS  
CAMDEN, NJ 08012  
ATTN R. W. ROSTROM, 13-5-2  
ATTN OLIVE WHITEHEAD

ROCKWELL INTERNATIONAL CORPORATION  
P.O. BOX 3105  
ANAHEIM, CA 92803  
ATTN J. L. MONROE, DEPT 243-027, DIV 031  
ATTN D/243-068, 031-CA31  
ATTN V. J. MICHEL

ROCKWELL INTERNATIONAL CORPORATION  
SPACE DIVISION  
12214 SOUTH LAKEWOOD BOULEVARD  
DOWNEY, CA 90241  
ATTN B. E. WHITE

ROCKWELL INTERNATIONAL CORPORATION  
5701 WEST IMPERIAL HIGHWAY  
LOS ANGELES, CA 90009  
ATTN B-1 DIV TIC (BAOB)

SCIENCE APPLICATIONS, INC.  
P.O. BOX 277  
BERKELEY, CA 94701  
ATTN FREDERICK M. TESCHE

SCIENCE APPLICATIONS, INC.  
PO BOX 2351  
LA JOLLA, CA 92038  
ATTN R. PARKINSON

SCIENCE APPLICATIONS, INC.  
HUNTSVILLE DIVISION  
2109 W. CLINTON AVENUE  
SUITE 700  
HUNTSVILLE, AL 35805  
ATTN NOEL R. BYRN

SCIENCE APPLICATIONS, INC.  
8400 WESTPARK DRIVE  
MCLEAN, VA 22101  
ATTN WILLIAM L. CHADSEY

SINGER COMPANY, THE  
ATTN: SECURITY MANAGER  
1150 MC BRIDE AVENUE  
LITTLE FALLS, NJ 07424  
ATTN TECH INFO CTR

SPERRY FLIGHT SYSTEMS DIVISION  
SPERRY RAND CORPORATION  
P.O. BOX 21111  
PHOENIX, AZ 85036  
ATTN D. ANDREW SCHOW

SPERRY RAND CORPORATION  
SPERRY MICROWAVE ELECTRONICS  
P.O. BOX 4648  
CLEARWATER, FL 33518  
ATTN MARGARET CORT

SPERRY RAND CORPORATION  
SPERRY DIVISION  
MARCUS AVENUE  
GREAT NECK, NY 11020  
ATTN TECH LIB

SPIRE CORPORATION  
P.O. BOX D  
PATRIOTS PARK  
BEDFORD, MA 01730  
ATTN ROGER G. LITTLE

DISTRIBUTION (Cont'd)

SRI INTERNATIONAL  
333 RAVENSWOOD AVENUE  
MENLO PARK, CA 94025  
ATTN GEORGE CARPENTER  
ATTN ARTHUR LEE WHITSON

SRI INTERNATIONAL  
306 WYNN DRIVE, N. W.  
HUNTSVILLE, AL 35805  
ATTN MR. HULLINGS

SYSTEMS, SCIENCE AND SOFTWARE, INC.  
PO BOX 1620  
LA JOLLA, CA 92038  
ATTN ANDREW R. WILSON

TEXAS INSTRUMENTS, INC.  
P.O. BOX 6015  
DALLAS, TX 75222  
ATTN TECH LIB  
ATTN DONALD J. MANUS, MS 72

TEXAS TECH UNIVERSITY  
P.O. BOX 5404 NORTH COLLEGE STATION  
LUBBOCK, TX 79417  
ATTN TRAVIS L. SIMPSON

TRW DEFENSE & SPACE SYS GROUP  
ONE SPACE PARK  
REDONDO BEACH, CA 90278  
ATTN O. E. ADAMS, R1-1144  
ATTN ROBERT M. WEBB, R1-2410  
ATTN R. K. PLEBUCH, R1-2078  
ATTN H. H. HOLLOWAY, R1-2036  
ATTN L. R. MAGNOLIA

TRW SYSTEMS GROUP  
P.O. BOX 368  
CLEARFIELD, UT 84015  
ATTN DONALD W. PUGSLEY

UNITED TECHNOLOGIES CORP  
NORDEN DIVISION  
HELEN STREET  
NORWALK, CT 06851  
ATTN TECH LIB

UNITED TECHNOLOGIES CORPORATION  
HAMILTON STANDARD DIVISION  
BRADLEY INTERNATIONAL AIRPORT  
WINDSOR LOCKS, CT 06069  
ATTN CHIEF ELEC DESIGN

VECTOR RESEARCH ASSOCIATES  
735 STATE STREET  
SANTA BARBARA, CA 93101  
ATTN W. A. RADASKY

WESTINGHOUSE ELECTRIC CORPORATION  
ADVANCED ENERGY SYSTEMS DIV  
P.O. BOX 10864  
PITTSBURGH, PA 15236  
ATTN TECH LIB

HARRY DIAMOND LABORATORIES  
ATTN DANIEL, CHARLES D., JR., MG,  
COMMANDING GENERAL (ERADCOM)  
ATTN RAMSDEN, JOHN J., LTC, COMMANDER/  
FLYER, I.N./LANDIS, P.E./  
SOMMER, H./OSWALD, R. B.  
ATTN CARTER, W.W., DR., TECHNICAL  
DIRECTOR/MARCUS, S.M.  
ATTN KIMMEL, S., PAO  
ATTN CHIEF, 0021  
ATTN CHIEF, 0022  
ATTN CHIEF, LAB 100  
ATTN CHIEF, LAB 200  
ATTN CHIEF, LAB 300  
ATTN CHIEF, LAB 400  
ATTN CHIEF, LAB 500  
ATTN CHIEF, LAB 600  
ATTN CHIEF, DIV 700  
ATTN CHIEF, DIV 800  
ATTN CHIEF, LAB 900  
ATTN CHIEF, LAB 1000  
ATTN RECORD COPY, BR 041  
ATTN HDL LIBRARY (5 COPIES)  
ATTN CHAIRMAN, EDITORIAL COMMITTEE  
ATTN CHIEF, 047  
ATTN TECH REPORTS, 013  
ATTN PATENT LAW BRANCH, 071  
ATTN GIDEP OFFICE, 741  
ATTN LANHAM, C., 0021  
ATTN CHIEF, 1010  
ATTN CHIEF 1020  
ATTN CHIEF 1030 (20 COPIES)  
ATTN CHIEF 1040  
ATTN CHIEF 1050  
ATTN CHEIF 340  
ATTN CHIEF, 210  
ATTN CHIEF, 0024